SUISUN MARSH STUDY

SOLANO COUNTY, CALIFORNIA

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

USDA-SCS-PORTLAND OR 1976

We are pleased to submit the completed report on the Suisun Marsh Study prepared by the United States Department of Agriculture, Soil Conservation Service, under a contract agreement with the United States Department of Interior, Bureau of Reclamation in cooperation with the Four Agency Delta Studies Group, the Suisun Marsh Technical Committee and the Suisun Resource Conservation District. It is part of an overall study of water related problems in the Sacramento-San Joaquin Delta and Suisun Bay area. It should not be considered as a final or recommended solution to any potential water quality problem in the Suisun Marsh.

SOIL CONSERVATION SERVICE
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INTRODUCTION

Suisun Marsh is a principal waterfowl wintering area in California. Over the years, reclamation, land utilization for intensive agriculture and urbanization have reduced waterfowl habitat in California from over five million acres to less than 500,000 acres. Complete elimination of the habitat has been prevented only by the concerned efforts of sportsmen, private landowners, and state and federal wildlife agencies, who have acquired and developed extensive areas for waterfowl use.

The value of the Suisun Marsh as waterfowl habitat and as a fishing and recreational area is well documented Arend, 1966, George et. al., 1965, Mall, 1969, Rollins, 1973, Skinner, 1972 and others. The problem of maintaining a proper salt balance is essential for preservation of the Suisun Marsh ecosystem. Intensified upstream water use, diversions directly from the Delta, and projected reductions in delta outflow will increase salinities surrounding Suisun Marsh and accentuate the problem of maintaining acceptable salt concentrations within the Marsh. Unless alternate water supplies of suitable quality and quantity can be developed in conjunction with a comprehensive marsh management program including improved physical facilities, only the least desirable food plants will persist. Such a vegetative change may result in a significant reduction in the waterfowl carrying capacity of the Marsh.

A review of the Suisun Marsh resource and its related problems resulted in a memorandum of agreement signed by the Bureau of Reclamation, the Fish and Wildlife Service, and the California Departments of Fish and Game and Water Resources July 13, 1970. This Four Agency Agreement provided for a study of Suisun Marsh to: (1) select a water supply and marsh management plan that will protect and enhance waterfowl habitat, (2) determine costs and benefits associated with a selected plan and define responsibilities among various interests, and (3) recommend a plan of action.

A contract between the Bureau of Reclamation and the Soil Conservation Service was executed in August, 1972. The contract provided that SCS prepare plans for a marsh management program using present water quality (1970 conditions), improved water quality (fresh water), and degraded water quality (highly brackish water). The signatories to the Four Agency Agreement agreed to supply funds and technical assistance as required in support of the SCS planning effort.

The Bureau of Reclamation and the Department of Water Resources have acknowledged that they have a major responsibility for maintaining present wildlife benefits in Suisun Marsh insofar as these benefits could be reduced by water project operations. Continuation of these benefits will require sustaining waterfowl food crop production at levels comparable with those which have existed in the Marsh. A management program to insure such production must regulate salt concentrations in the soils of the Marsh. This program could include (1) physical works which efficiently utilize water to control soil salinity and (2) a supply of imported water either (a) to reduce water salinity in the channels of the Marsh or (b) to be applied directly to marshland to support desirable plant growth.

This report provides basic data on ecological factors involved in Suisun Marsh, an inventory of present wildlife benefits, and physical works and management alternatives required to maximize wildlife benefits under three conditions of water quality.

DESCRIPTION OF THE AREA

Suisun Marsh, one of the few major marshes remaining in California, is an intricate land-water area of marshland, ponds, sloughs, and estuaries which furnish habitat for a variety of plants and animals. In size, it consists of approximately 57,000 acres of marshland and 27,000 acres of bays and waterways. These wetlands are a unique and highly productive interface between fresh and salt water environments.

Suisun Marsh is located in southern Solano County, south of the cities of Fairfield and Suisun. It is bounded on the south by Suisun Bay, Honker Bay and the confluence of the Sacramento and San Joaquin Rivers, on the west by the Luther Gibson Freeway (State Hwy. 21) running from Benicia to Cordelia, on the north by Cordelia Road to the city of Suisun, around the Petrero Hills to Denverton, on the east from Denverton along Shiloh Road to Collinsville.

CLIMATE

The winters in Suisun Marsh are mild and wet and the summers, warm and dry. The rainy season starts generally in November and continues into March. The average annual rainfall recorded over a 38 year period at Suisun was 19.79 inches. Some frost occurs in the Marsh and summer temperatures can often exceed 90°F. The climate is tempered generally by cool moist winds blowing inland from the Pacific Ocean and San Francisco Bay through Carquinez Straits. Winds blow consistently during late spring, summer and early fall, thus the Indian name, Suisun, meaning "West Wind."

TOPOGRAPHY

Suisun Marsh lies adjacent to the Sacramento Valley within a large notch in the Coast Ranges and occupies a relatively narrow and broken plain just to the north of Suisun Bay. From that Bay, waters of the Central Valley drain through Carquinez Strait to San Francisco Bay. A network of tidal sloughs, principally tributaries of Suisun and Montezuma Sloughs, together with many drainage sloughs crosshatch the marshlands. About ninety percent of the marshland is now enclosed by a system of low levees. Levees range in height from four to eight feet above ground level. Most of the Marsh lies at an elevation at or below mean tide elevation. Hills surrounding the Marsh on the north and west rise to elevations of 800 to 1100 feet above sea level. To the east, the Potrero and Montezuma Hills rise 300 to 400 feet above the Marsh. Drainage from the hills is through the Marsh and into Suisun Bay. Major streams carrying runoff from surrounding hills and flood plains are Green Valley, Suisun, Ledgewood, Laurel, McCoy, Union and Denverton Creeks.

GEOLOGY AND GEOGRAPHY

Suisun Marsh is relatively young, geologically. It was formed by the sea, the rivers and the vulcanism of the late Pliocene and Pleistocene periods. In its present form, the Marsh is an extension of San Francisco Bay with features of the Great Central Valley.

In late Miocene and early Pliocene, the area that is now the Great Central Valley was a shallow sea. Successive uplifts and gradations slowly raised the fault blocks of the west ranges and isolated the Central Valley. A major orogeny, occurring at the end of the Pliocene, thrust up the Coast Ranges. The sea receded from the interior, and internal folding occurred among the younger sediments of the region. During the early Pleistocene, a time of erosion and gradation, the drainage of the Great Central Valley escaped to the sea by much the same route that it follows today.

In the mid-Pleistocene, mountain-building laid the framework for the landscape we see today. In the immediate vicinity of San Francisco Bay, block faulting on a large scale took place, outlining the trough of the Bay which was later inundated by the sea. The Sacramento-San Joaquin River, however, maintained its course to the sea across these rising blocks, downcutting narrowly in the faults of the North Bay to form the present Carquinez Straits.

During this period, occurred the downfolding of the underlying Cretaceous beds east of the Coast Range blocks. As this basin was developed, a gentle subsidence in the Bay and coastal areas began and the landscape assumed the form we know today. Into the downfolded basin east of Carquinez Straits and the Vallejo Hills the river deposited its sediments creating the lands of the Suisun Marsh. Minor geological uplifts, from the mid to the late Pleistocene, completed the framing of the Marsh. During this period, an orogeny uplifted the Potrero Hills and further isolated Suisun Marsh from the Great Central Valley.

HISTORY OF DEVELOPMENT

Suisun Marsh was originally built by silt deposits from overflow waters of Suisun Slough, Montezuma Slough and the Sacramento-San Joaquin River systems. It was a typical brackish water marsh influenced by tidal sloughs (George et. al., 1965). Large portions of land were submerged daily and limited areas of higher ground were inundated by seasonally high tides. Flood waters during winter and spring covered most of the Marsh and provided fresh water in the channels for a period of time. Historically, water quality in the sloughs has varied considerably with season and from year to year.

Development of Suisun Marsh and adjacent areas began during the 1850's on a small scale by individuals who constructed low sod levees. During the 1860's, reclamation increased rapidly and more than 20 reclamation districts were formed. In the period between 1860 and 1880, each of these districts completed partial reclamation systems with levees which protected enclosed lands from normal tidal flooding. The bulk of reclamation was completed before 1920, and, by 1930, 44,600 acres had been developed in Suisun Marsh.

Prior to reclamation, beef and dairy cattle were pastured in the higher areas of the Marsh. Agricultural developments, in spite of reclamation improvements, were largely unsuccessful because of poor drainage and the accumulation of salts in the soil. Current agricultural practices include continued cattle production and limited dry farming of grain crops where suitable soils exist.

Reclaimed marshlands proven unsuitable for agriculture have, for the most part, been converted to private duck clubs and state wildlife management areas. The splendid duck hunting and the nearness of the Marsh to large metropolitan centers have made these wetlands more valuable as open space for wildlife than for any other purpose.

Rapid population growth in the San Francisco Bay Area has exerted pressure on all open space that can be readily developed. Industrial developments and the expanding communities of Cordelia, Benicia, Fairfield and Suisun adjacent to the Marsh, give concern to individuals and governmental bodies involved with planning and management of resources in the area. The State Legislature has provided for the acquistion of land and easments within and around Suisun Marsh to ensure its protection and prevent encroachment that will reduce the value of its resources (Senate Bill No. 1981, September 27, 1974).

CENTRAL VALLEY WATER DEVELOPMENT

Availability of fresh water in Suisun Marsh is dependent upon precipitation and use in the Sacramento and San Joaquin River Basins. The average annual outflow from these basins prior to water development was 33.6 million acre-feet (Department of Water Resources, 1960). Fresh water outflows, resulting primarily from winter storms, prevented sea water from entering marsh channels except during certain months. During these months, the Delta flows were greatly reduced and this allowed salt water intrusion for brief periods, even under historical conditions.

About the time marsh reclamation began, significant water development for agricultural and municipal use was occurring in the Central Valley. Construction of dams began before 1870 and continued at an increasing rate until an unprecedented level was achieved in the period between 1940 and 1970 (Skinner, 1972). Initially, these developments did not substantially alter the natural runoff pattern into Suisun Bay. However, by 1930, storage and diversion capabilities reached 10 million acre-feet. Currently, proposed and existing federal and state water projects have a combined storage capacity on streams within the Central Valley of approximately 20 million acre-feet. In addition, private storage in the valley probably exceeds 10 million acre-feet. Storage alone is not a major concern, but the presence of structures which facilitate consumptive use and diversion of water to other basins have already reduced Delta outflow from 33.6 to 15.9 million acre-feet.

Consumptive use and exportation of water from the Central Valley is of far more concern than storage in terms of actual impact on environmental conditions, since these factors affect its availability for use in Suisun Marsh. Approximately 85 to 90 percent of the consumptive use of water is for agricultural crops. Drainage from these lands are high in salts and increase salinity in the Delta. As upstream development and further Delta diversions deplete outflows of fresh water, water quality within Suisun Marsh will become a more critical problem.

IMPORTANCE OF SUISUN MARSH

California is the main wintering grounds of most waterfowl populations using the Pacific Flyway. Suisun Marsh and the Delta have always been an important part of the waterfowl habitat in

California. These tidal areas have always had water and have provided the most dependable habitat, particularly during fall when the large flood basins of the Sacramento and San Joaquin Valleys were often dry. The value of Suisun Marsh as waterfowl habitat increased after portions of the Sacramento and San Joaquin Rivers were leveed to prevent flooding. "Old-timers" used to tell of the large flights of ducks that poured out of the Marsh and flew north as far as Colusa to feed in the barley stubble in the fall. In more recent years, (1950) the California Department of Fish and Game purchased and developed the Grizzly Island Wildlife Management Area to provide additional habitat that would hold more ducks in the Marsh during the early fall in order to alleviate duck depredation on unharvested rice.

The first migrants from the north, usually pintails, arrive in the Marsh as early as August. By mid-September, over a half-million birds have arrived and by December, the bulk of the migrating waterfowl have reached California. These waterfowl move up and down the Valley exploiting the most favorable habitat. However, band recovery data from pintails has shown that these birds remain in the Marsh throughout the fall hunting season and most of the winter (Arend, 1966 and George et. al., 1965). This information indicates that the Marsh may be the center of the wintering pintail population.

In "dry years" when winter rains do not begin before midwinter the Marsh may provide habitat for over a quarter of the waterfowl in the Central Valley (Table 1). Population estimates from aerial surveys (Tables 2 and 3), are given for major species found in Suisun Marsh and the Central Valley. These estimates clearly demonstrate that the pintail is the most numerous duck using the Marsh.

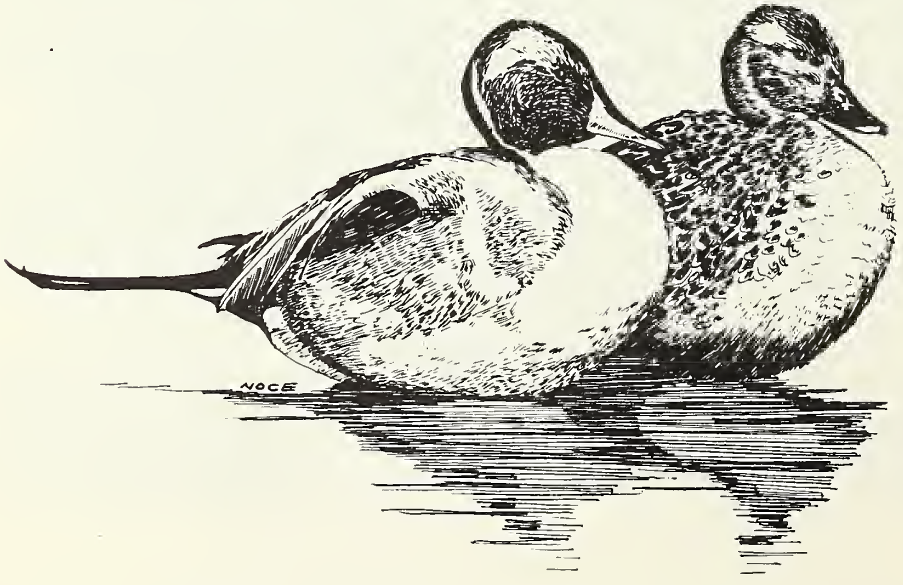

TABLE 1
DUCK POPULATION ESTIMATES FOR 1967 1/

Date	Suisun Marsh	Central Valley	Percent of Total
September 15, 1967	112,000	791,000	14
October 11, 1967	191,000	2,069,000	10
October 25, 1967	398,000	1,669,000	24
November 8, 1967	404,000	2,237,000	18
November 22, 1967	786,000	2,967,000	26
December 6, 1967	773,000	3,026,000	25
January 10, 1968	328,000	4,326,000 2/	8

1/ From data supplied by J. R. LeDonne, California Department of Fish and Game, Sacramento, California.

2/ Statewide Total. By this date most ducks were in Central Valley.

Suisun Marsh is not an important waterfowl breeding area from a flyway standpoint. However, ducks do nest in the Marsh and are important locally. Production is quite low (Anderson, 1960). The primary species breeding in the marsh and their numbers have been summarized in Table 4 from surveys conducted by the California Department of Fish and Game. Several factors contributing to the low breeding populations, such as excessively heavy vegetation, large cracks in the soil, abrupt shore lines, lack of permanent ponds and predation, have been discussed by Anderson (op. cit.). However, a literature search by Griffith (1963) and an incomplete field trial with captive wild ducklings indicate that salinities in the Marsh, particularly in sloughs and ponds during late spring and summer, could be highly toxic to ducklings. Adult ducks are able to excrete excess salt (Cooch, 1964), but apparently, young birds cannot. The lack of significant waterfowl breeding populations around San Francisco Bay and the serious decline in the number of breeding pairs in the Napa Marsh (Table 5) as it was converted to evaporation ponds for salt production, tends to support the contention that salinity is the limiting factor.

The Suisun Marsh is important as a recreation area. It is the third most productive waterfowl harvest area in the state (George et. al., 1965), and duck hunting in the Marsh provides 150,000 man days of recreation annually (Rollins, 1973). It also provides opportunities for recreational fishing, boating, nature study and other activities.

TABLE 2

MID-SEPTEMBER INVENTORY OF WATERFOWL 1/
USING THE SUISUN MARSH, 1953 THRU 1973

Year	Species			Total	Total For Central Valley
	Pintail	Mallard	Other Ducks		
1953	87,000	2,000	1,000	90,000	684,000
1954	11,000	5,000	2,000	18,000	541,000
1955	35,000	1,000	1,000	37,000	724,000
1956	20,000	3,000	2,000	25,000	1,151,000
1957	102,000	2,000	1,000	105,000	2,034,000
1958	129,000	12,000	14,000	155,000	1,647,000
1959	18,000	1,000	1,000	20,000	1,471,000
1960	30,000	2,000	4,000	36,000	1,477,000
1961	15,000	2,000	4,000	21,000	758,000
1962	21,000	2,000	7,000	30,000	670,000
1963	2,000	1,000	2,000	5,000	707,000
1964	4,000	2,000	3,000	9,000	444,000
1965	4,000	2,000	2,000	8,000	509,000
1966	35,000	7,000	2,000	44,000	819,000
1967	96,000	8,000	8,000	112,000	791,000
1968	26,000	26,000	8,000	37,000	781,000
1969	30,000	2,000	4,000	36,000	910,000
1970	13,000	2,000	5,000	20,000	986,000
1971	34,000	3,000	1,000	38,000	792,000
1972	18,000	3,000	1,000	22,000	815,000
1973	36,000	4,000	4,000	44,000	576,000
Average	36,000	3,000	3,000	42,000	895,000

1/ From Data Supplied by Frank M. Kozlik, California Department of Fish and Game. Pacific Flyway Reports, 1953 thru 1973.

TABLE 3

WINTER INVENTORY OF WATERFOWL POPULATIONS FOR THE SUISUN MARSH 1954 THRU 1974 1/

	SPECIES										
YEAR	PINTAIL	AMERICAN WIDGEON	SHOVELER	MALLARD	CANVASBACK	OTHER DUCKS	TOTAL DUCKS	GEESE	COOTS	TOTAL WATERFOWL	STATEWIDE TOTAL
1954	192,000	50,000	9,000	46,000	3,000	14,000	314,000	12,000	43,000	369,000	5,854,000
1955	462,000	21,000	74,000	21,000	20,000	92,000	690,000	10,000	26,000	726,000	5,372,000
1956	116,000	48,000	19,000	1,000	--	10,000	194,000	17,000	24,000	235,000	6,574,000
1957	538,000	35,000	14,000	27,000	1,000	13,000	628,000	77,000	8,000	713,000	5,178,000
1958	71,000	12,000	12,000	22,000	--	11,000	128,000	25,000	70,000	223,000	6,681,000
1959	377,000	66,000	10,000	53,000	--	22,000	528,000	46,000	160,000	734,000	6,327,000
1960	247,000	25,000	39,000	16,000	6,000	30,000	363,000	87,000	71,000	522,000 2/	5,073,000
1961	159,000	24,000	9,000	14,000	6,000	30,000	215,000	24,000	94,000	333,000	5,396,000
1962	183,000	32,000	17,000	13,000	2,000	20,000	267,000	59,000	63,000	389,000	4,815,000
1963	119,000	11,000	29,000	19,000	--	19,000	197,000	40,000	40,000	277,000	5,044,000
1964	95,000	17,000	16,000	15,000	1,000	30,000	174,000	42,000	29,000	245,000	4,808,000
1965	21,000	3,000	15,000	5,000	--	7,000	51,000	3,000	12,000	66,000	5,835,000
1966	127,000	24,000	30,000	6,000	--	6,000	193,000	1,000	3,000	197,000	3,973,000
1967	101,000	7,000	5,000	--	6,000	3,000	122,000	3,000	29,000	154,000	5,334,000
1968	175,000	52,000	40,000	25,000	--	22,000	314,000	--	14,000	328,000	4,326,000
1969	84,000	4,000	26,000	1,000	2,000	25,000	142,000	1,000	4,000	147,000	4,229,000
1970	52,000	5,000	5,000	2,000	--	1,000	65,000	1,000	21,000	87,000	6,015,000
1971	43,000	3,000	29,000	22,000	2,000	1,000	100,000	1,000	6,000	107,000	7,607,000
1972	121,000	3,000	9,000	--	2,000	1,000	136,000	8,000	3,000	147,000	5,954,000
1973	2,000	--	4,000	--	6,000	1,000	13,000	6,000	9,000	28,000	5,742,000
1974	27,000	1,000	3,000	1,000	1,000	1,000	34,000	9,000	13,000	56,000	6,742,000
Average	158,000	21,000	20,000	15,000	3,000	16,000	232,000	22,000	35,000	290,000	5,566,000

1/ From data supplied by Frank M. Kozlik, California Department of Fish and Game

2/ Total includes 1,000 swans

TABLE 4

BREEDING PAIRS OF WATERFOWL USING THE SUISUN MARSH, 1949 THRU 1972 1/

Year	Waterfowl Species							
	Mallard	Gadwall	Cinn Teal	Shoveler	Pintail	Redhead	Other Ducks	Total Ducks
1949	3490	190	70	-	-	-	50	3800
1950	1910	180	50	-	-	-	180	2320
1951	980	340	100	-	-		20	1440
1952	3440	480	580	-	-	-	180	4680
1953	1400	200	100	-	-	-	140	1840
1954	500	100	100	-	-	-	90	790
1955	660	140	140	-	-	-	60	1000
1956	1100	80	130	-	-	-	50	1360
1957	760	70	80	-	-	-	190	1100
1958	1340	110	90	-	-	-	80	1620
1959	760	270	110	-	-	-	100	1240
1960	1150	370	180	-	-	-	40	1740
1961	550	350	140	-	-	-	20	1060
1962	450	280	70	-	-	-	50	850
1963	800	300	280	70	-	-	120	1570
1964	1250	460	260	30	30	30	-	2060
1965	1860	770	530	30	-	30	-	3220
1966	1120	280	160	60	70	-	-	1690
1967	1250	280	110	-	50	10	70	1770
1968	760	230	180	20	30	-	-	2210
1969	1360	160	140	20	60	-	30	1770
1970	1570	430	340	200	240	20	80	2880
1971	2050	270	390	60	70	30	60	2930
1972	1250	390	590	-	40	-	20	2290

1/ From Pacific Flyway Reports, California. Frank M. Kozlik, California Department of Fish and Game, Sacramento, California.

THE MARSH ENVIRONMENT

There are several ecological factors involved in the development of the Suisun Marsh vegetation which must be understood to properly manage the Marsh for waterfowl and recreational use. It is important to understand that a marsh is an intermediate state between a lake or estuary and upland soil. This phenomenon, described by Weaver and Clement (1938), Teal and Teal (1969) and others, occurs as a result of sedimentation and the accumulation of plant and animal remains. One of the objectives of a marsh management plan for waterfowl use should be to retard, or where possible, reverse this successional process to prolong the life of the Marsh.

TABLE 5

BREEDING PAIRS OF DUCKS - NAPA MARSH 1/

Year	Mallard	Gadwall	Cin. teal	Pintail	Other Ducks	Total
1949	575	40	0	5	10	630
1950	806	0	9	83	954	
1951	560	73	0	7	7	647
1952	480	130	30	30	180	850
1953	440	90	10	140	200	880
1954	400	140	30	20	170	760
1955	80	10	10	0	30	130
1956	70	10	0	10	100	190
1957	110	50	0	0	180	340
1958	2/ 30	10	10	0	60	110

1/ Data from US Fish and Wildlife Service. Waterfowl populations and breeding conditions, summer, 1951 thru 1958. Special Scientific Reports.

2/ Counts discontinued after 1958.

ENVIRONMENTAL CONDITIONS

Under tidal influence, the deposition of sediment is quite important. Flood waters flowing through the Delta are the main source of sediment. Also, the ebb and flow in the tidal channels erodes, transports and redeposits sediments almost continuously, eventually depositing much of the material along the banks to form natural levees (Prestrong, 1972). These levees lead to the formation of salt pans (shallow catchment basins in the center of islands and on flood plains between the headlands and the edge of tidal sloughs). Marsh vegetation accentuates this process by slowing down the current across the natural levees, inducing floculation of the coloidal material and by adding large masses of undecayed vegetation annually. However, the higher tides continue to top the natural levees and the currents pickup and recycle nutrients. Bacteria, phytoplankton, zooplankton, higher plants and animal life, depend on these nutrients for their existence. This tidal action also promotes a high dissolved oxygen content in both the water and the soil exposed at low tide. All of these interactions combine to make the tidal marsh one of the most productive ecosystems (Odum, 1961).

Man-made levees have been added to the natural levees throughout most of the Marsh. These levees cutoff normal tidal action and have created a system of closed basins where the water level within them is largely controlled by tide gates. Under these conditions, sedimentation is reduced considerably, while the accumulation of organic matter may be increased, depending on the management of the individual basins. Nutrient recycling patterns may be slowed down or altered drastically.

Newly leveed basins that are de-watered more or less permanently go rather abruptly from an estuarine or marsh successional stage to an upland soil stage. This drastic change in the environment seriously affects the established plant and benthic community. Most species involved can not survive such a change and are eventually replaced by other communities.

With the de-watered condition, several other changes take place. Sedimentation ceases; the dead vegetation begins to decay and as the soil dries, the organic matter in it begins to oxidize more rapidly. Subsidence begins to occur rather than accretion. Polysulphides, which are formed in the highly organic soil while covered with brackish water and in the absence of oxygen, also begin to oxidize as the soil dries. The result is a "cat clay" condition (Neely, 1958) where the soil pH drops drastically as sulfuric acid is formed. In severe cases, this condition alone can eliminate most vegetation, and probably was a contributing factor in the failure of agricultural crop production on some of the islands in the Marsh.

Salt accumulation in the soil is a factor of major importance. On the higher areas with mineral soil (Valdez series) such as Grizzly Island, the leaching action of rainfall is sufficient to maintain a favorable salt balance. However, in the lower areas, particularly those with peat soils (Suisun series), capillary action and hydrostatic pressure bring salty water to the surface, making it very difficult to maintain a suitable salinity.

Some of the newly leveed islands were re-flooded permanently. Tide gates were adjusted to maintain a stable water level by allowing tide water to enter the ponds as needed during high tides. The salinity level was maintained by allowing some water to discharge during low tides. Under these stabilized conditions, marsh vegetation became re-established and grew vigorously, encroaching upon the shallower ponds and building up a thatch of vegetation which periodically was burned. Some silt entered the ponds with the tidal water inflow, but little left the ponds. The recycling of nutrients depended upon the slow decomposition of the vegetation, unless burning was practiced, and most of the nutrients remained in the ponds.

The management of most of the leveed acreage in the Suisun Marsh evolved to a seasonally flooded pattern, i.e., flooded in the fall for the hunting season and then drained so as to be dry from May 1 to October 1 in the interest of mosquito abatement. In many cases drainage was incomplete and saline water was allowed to evaporate within the ponds, increasing the salt load. The high salt concentration combined with low soil pH due to "cat clay" formation, and the seasonal pattern of winter flooding and summer droughts, produced many ponds that, by 1950, were devoid of vegetation. Some vegetation developed around the margins of ponds where the leaching of salts by rainfall occurred, but the number of plant species involved was quite limited. Under these conditions, some sediment entered the ponds during the fall flooding cycle, with little leaving in the drain cycle at the end of the hunting season. Recycling of nutrients was also limited. In general, less vegetation was produced than occurred under either tidal or permanently flooded conditions. The break down of organic matter was slowed by the harsh environmental conditions, particularly the high salt content. However, decomposition was sufficient generally to balance accretion (peat formation and sedimentation) and possibly cause slight subsidence.

Management patterns of seasonally flooded ponds varied. One important variation was the practice of circulating water through the ponds during the fall and winter by adjusting the tide gates as was done on the permanently flooded ponds. This tended to reduce the accumulated salt load and buffer the low soil pH. The result was a more diverse and productive plant community.

Another factor was the periodic flooding that occurred when the peak of a heavy flood flow coincided with the arrival of a particularly high tide causing the water to top most levees in the Marsh. The floods of 1955 and 1973 are examples. Such floods carry off large amounts of salt thus freshening up the Marsh environment, bringing in more sediment and probably recycling some nutrients. Following such floods, more fresh water plants appear in the Marsh and plant growth is stimulated.

MARSH ECOLOGY

Plants and plant communities respond to environmental conditions in the Marsh, evolving and diversifying to the extent that they occupy almost every niche. However, individual species usually are adapted to a specific or narrow range of conditions. Most marsh plants are water-tolerant or water-loving plants (hydrophytes) and have adapted to low oxygen content of saturated soils (Delevoryas, 1966). Most upland plants cannot tolerate this low oxygen condition. Similarly, most marsh plants cannot tolerate dry, xerophytic conditions. However, individual species vary in their tolerance to degrees of wetness and to depth and duration of flooding. Marsh plants also vary in their tolerance to salt concentrations. Those which have a high degree of salt tolerance are called halophytes. The differential response of the various plant species to the environmental conditions in the Marsh is important in determining where the plants will grow. Differential plant responses can be used as a guide in manipulating or modifying environmental conditions to produce the desired plant composition.

Plant species vary in the way they compete or survive. Annuals rely solely on seed for survival. In general they have fairly large seeds with a large endosperm which supplies the energy reserve necessary for good seedling vigor following germination. Annuals are usually invaders which spread readily into new soil or bare ground. Many annuals are choice waterfowl food plants and are desirable in the Marsh, but they tend to be crowded out by perennial plants. A key to perpetuating annuals is to retard successional development or to return the soil to the "bare ground stage."

Perennial marsh plants tend to dominate the Marsh. Because they do not have to start from a seedling each year as annuals do, they generally do not have to expend as much of their energy on seed production to survive. In fact, some produce practically no seed but spread vegetatively. The wet marshy soil is ideal for this type of growth and so it is not surprising that most of the dominant marsh plants are these "sod-formers." The marsh plants that spread mainly by vegetative means (rhizomatous) are slow to invade bare ground, but once there, they hold on aggressively, often to the exclusion of other plants. Olney bulrush (Scirpus Olneyi) is a good example of this. The food these plants contribute is mostly in the form of tender shoots, fleshy roots or tubers. The seed often is too small to be of value to waterfowl or the total amount produced is insignificant. The result is that these sod-formers tie up large amounts of nutrients, especially in peat formation, that are not recycled for years. It is desirable to slow down the peat formation process and/or periodically reverse the process by decimating the sod-formers in one way or another.

The foregoing are generalizations. Some annuals have small seeds and some perennials have fairly large seeds, such as those of alkali bulrush (Scirpus robustus). The exceptions usually occur as a result of further specialization which enables the plant to fill some special niche and thus compete successfully with other plants in the community.

ECOLOGICAL STATUS OF SOME IMPORTANT PLANTS OF THE MARSH

Plants that will be discussed here range from cultivated and self-perpetuating annuals to dominant sod-producing perennials and submerged aquatics. Also, they range from more or less "fresh water" species to extremely salt tolerant halophytes which are important under varying conditions of water quality. The following species are important as competitors for space or because of their desirability as waterfowl food plants.

BARLEY

Barley (Hordeum vulgare) is a domesticated annual that has been planted primarily on Grizzly Island on Valdez soils for many years. It is moderately salt tolerant, and requires seed bed preparation and planting each year to produce sustained yields. Young plants are grazed by geese, widgeon and coots, and the seed is a choice food for most waterfowl.

FAT HEN

Fat hen (Atriplex patula var. hastata) is an annual herb that occurs extensively. It is a prolific seed producer and a choice feed of pintail and other ducks. It grows best during the summer and fall on disturbed upland soil, particularly on Grizzly Island and on dry pond bottoms where there is little competition, or on islands or unflooded soil around permanently flooded ponds. Seedlings will occupy any opening in other vegetation where the soil is exposed and where the soil salinity is less than 12.0 millimhos electrical conductivity (mmhos E.C.)-7.7 parts per thousand (0/00) total dissolved solids - in the first 6 inches of soil (George, et. al., 1965). Mall (1969) found dominant stands occupying soil with a salinity range of 12.8 to 48.2 0/00 (19.2 to 73.8 mmhos E.C.). It will not tolerate extensive flooding during the growing season and fall flooding ends the growth in the duck ponds.

KNOTWEEDS

Silver-sheathed knotweed (Polygonum argyrocoleon) and wire grass (P. aviculare) are two annual herbs that occur on disturbed upland soils, particularly on Grizzly Island where barley is planted. They occasionally appear in dry ponds where the salinity and plant competition is low.

SMARTWEEDS

Nodding smartweed (Polygonum lapathifolium) and dotted smartweed (P. punctatum) are two duck food plants that appear in the Marsh to a limited extent. They are only slightly salt tolerant and are found mainly along ditches and wet areas where the osmotic pressure in the soil is fairly low. They are most apparent after seasons of high precipitation when flood water has freshened the Marsh, and would be much more common if fresh water were supplied to the Marsh.

BARNYARDGRASS

Barnyardgrass (watergrass-Echinochloa crusgalli) is another good waterfowl plant that occurs in the Marsh only in the fresher areas. It is an annual grass. The seed will germinate in brackish water (George, et. al., 1965) but seedings will not survive where the salinity is more than 5 0/00 (7.5 mmhos E.C.). In fresh marshes, it is gradually crowded out by perennials and cultural methods must be employed to perpeturate the plant in significant quantities.

Other annual grasses such as ryegrass (Lolium sp.), soft chess (Bromus mollis), ripgut (Bromus rigidus) and wild barley (Hordeum sp.) are common species in the Marsh on upland soils that are not flooded. They are not particularly salt tolerant and occur where drainage is sufficient to prevent the accumulation of salt in the surface soil. They are of little importance as duck food, but provide some grazing for geese and coots. They also successfully compete for space with other annuals that are good wildlife food plants.

BRASS BUTTONS

Brass buttons (Cotula coronopifolia) is a highly adaptable perennial plant. It is quite salt tolerant (George, et. al., 1965). It germinates early in the season like a winter annual and may be found growing in shallow water (Mason, 1957) like an aquatic. By mid-May, it is in full flower. As the ponds dry up, the seed matures and most of the plants die. It is a very important waterfowl food plant in the Marsh, rated second in overall use and selection by Mall, (1969) and Browning (George, op. cit.). It reaches its highest development in shallow ponds in the spring where winter flooding has precluded the growth of annual grasses and summer drought and moderate soil salinity - less than 49.0 mmhos E.C. in the surface soil (George, op. cit.) - has combined to restrict competition of other hydrophytes.

ALKALI BULRUSH

Alkali bulrush (Scirpus robustus) 1/ is a sod-forming emergent perennial that grows in shallow water - usually less than one foot deep - and on moist soil. It produces a fairly large seed in significant quantities. This plant is one of the more salt tolerant plants. Mall (1969) observed dominant stands that tolerated soil salinities up to 32.5 0/00 (48.8 mmhos E.C.), and non-productive stands as much as 51 0/00 (76.5 mmhos E.C.), George and others (1965) found it growing where the average soil salinity in the first six inches of soil reached as high as 68.9 mmhos E.C. (44 0/00). However, Mall (op. cit.) found that seed production was the highest in the salinity range of 7 0/00 to 14 0/00 (11.0 to 21.0 mmhos E.C.) and that seed production ceased when the salinity reached or exceeded 26 0/00 (39.0 mmhos E.C.). At higher salinities, the plant goes dormant. It will grow in fresh water, but does not compete well with other tall hydrophytes such as cattails (Typha sp.) and hardstem bulrush (Scirpus acutus). In test plots at the SCS Plant Materials Center at Pleasanton, California, yields as high as 3,500 pounds per acre were produced in fresh water. In two similar plots with 10 0/00 (15.8 mmhos E.C.) salinity seed production was reduced by approximately one-third. New stands produce more seed than well established sod-bound stands. In small test plots at the Pleasanton Plant Materials Center on Pleasanton gravelly loam, the annual seed production decreased each year following establishment under identical conditions except for minor variations in the weather pattern. The average annual yield from nine plots was 2,400 pounds per acre in 1969, 1,200 in 1970, 1,000 in 1971 and 900 in 1972. Two of the nine plots showed an increase the 4th year which would tend to indicate the

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1/ Alkali bulrush is considered a separate species-S. paludosus- by some authors such as Hotchkiss (1970). Actually the taller coastal form-typically S. robustus-and the shorter inland form (typically S. paludosus) both occur in the Suisun Marsh, often side by side. Mason (1957) could find no consistent characters which would serve to maintain the two forms as distinct entities.

older root material was beginning to break down and the recycling of nutrients was progressing. (From annual technical reports SCS, Plant Material Center, Lockeford, California.)

Ecologically, alkali bulrush acts as a halophytic invader (Nelson, 1954 and Palmisano and Newson, 1967). Over a long period of time the plant has developed in saline areas where fluctuations in salinity and water levels (drought periods) have regularly decimated the less tolerant vegetation. Part of its adaptive advantage is early development in the spring that produces seed before drought or high salinity forces dormancy. The seed has a tough seed coat and will persist for years in the soil waiting for favorable conditions to occur. Usually, the seed will not germinate in salty water (George, et. al., 1965, and Palmisano and Newson, op. cit.). Newly seeded ponds must be flooded for at least two weeks before germination occurs (George, 1963 and O'Neill, 1972). Thus, the vital seed reserve is protected from premature germinations under poor conditions - too much salt or too little water. The plant will usually re-invade newly flooded salt flats or salt pans, when conditions freshen before competitors such as cattails and tules. Because of its salt tolerance, alkali bulrush can also occupy a site longer than most of its competitors if the environment becomes more saline. Actually, salinity management can be used to help perpetuate alkali bulrush stands where conditions can be monitored and controlled.

This useful plant is one of the most important waterfowl food plants. Mall (1969:15) in his study of the Suisun Marsh reported that alkali bulrush had "the highest overall use and selection values of the 35 plant species recorded." Browning rated it similarly in his discussion of food habits of ducks in the Marsh (George, et. al., 1965).

CATTAILS

Cattails (*Typha* sp.) are rhizomatous perennials which produce an abundance of small, wind-borne seed. This latter characteristic gives these plants the capability of being serious invaders of exposed mud flats and shallow water areas. Once a cattail seedling is established, it begins to spread vegetatively. Because of their height and vigor, cattails tend to dominate most other emergent marsh plants in shallow, fresh to moderately brackish ponds. They are not competitive in dry soil nor in very brackish water. The small cattail seed furnishes little or no food for ducks. The roots and tender shoots of young stands furnish food for geese, but dense stands of mature plants seldom are used for food except by muskrats. Mallards frequent ponds ringed with cattail, however most ducks will not decoy into cattails.

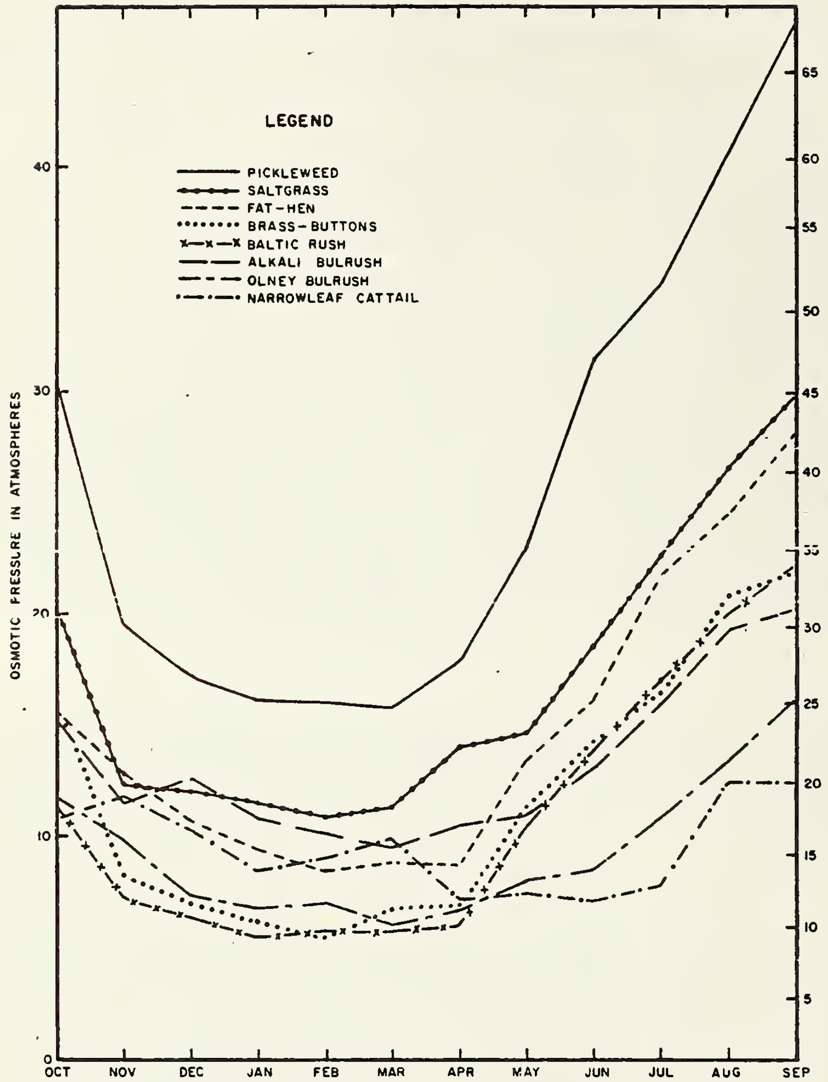
Narrowleaf cattail (Typha angustifolia) is the most salt tolerant of the four species of cattail listed for the Marsh and is probably the most widespread for this reason. In Mall's (1969) study, the mean monthly soil salinity in the root zone varied from 11.6 0/00 (18.0 mmhos E.C.) during April, May and June to a high of 20 0/00 (30.0 mmhos E.C.) during September (Figure 1). George et. al., (1965) indicated that the approximate maximum soil salinity cattail could tolerate was 40.0 mmhos E.C. (27 0/00). Mall (op. cit.) also observed that long periods of submergence favored the development of this plant as did soils with a high organic content. He also found dominant stands of cattail had a high percentage of soil moisture in the root zone (0-12 inches) throughout the growing season, averaging about 300 percent, April through September. This confirms the fact that this plant has developed ecologically as an aquatic plant with a narrow range of adaptability for salt. If conditions become too adverse, it dies out and relies on the mobility of wind-blown seed from other areas to re-invade the site if and when conditions again become tenable. Cattail can grow in water as deep as 42 inches (Rollins-personal communication) and it can tolerate deeper flooding for short periods. However, the plant must have contact with the air to survive. Cutting the stems below the water line greatly increases mortality and can be used as a means of control.

TULES

Hardstem bulrush (Scirpus acutus) and California bulrush (Scirpus californicus), commonly referred to as tules, are emergent perennial marsh plants which grow primarily along the sloughs, channels and ditches. However, they become established in ponds which have remained flooded during most of the summer. They are sod-formers, spreading vegetatively once a seedling is established, and will grow in peat or mineral soil. The seed is fairly small for bulrushes and relatively small amounts of seed per acre are produced (See section on Waterfowl Food Production). The seed is taken by waterfowl when available - particularly green-winged teal.

Tules are only moderately salt tolerant. George et. al., (1965) found hardstem tules growing in a range of soil salinity for the root zone (0-12 inches) of 2.0 to 22.0 mmhos E.C. (1.5 to 33 0/00). Both species grow along the Carquinez Straits at Benicia where records show that the salinity reaches the polyhaline range (Skinner, 1972). In the tidal zone, California bulrush invades deeper water than hardstem bulrush. Both species will tolerate water depths in ponds from zero to three feet deep. Again, these plants are slow to invade new areas, but once the plants are established, they maintain dominance over most other marsh plants. They are valuable along the outside levees where they buffer wave

FIGURE 1



Mean monthly salt concentrations in the root zone (0 to 12 in.) for dominant growth sites of eight Suisun Marsh plants. Values are composited from two growing seasons.

From Mall, 1969. Soil-water-salt relationships of waterfowl food plants in the Suisun Marsh of California, page 37.

action, helping to prevent erosion. Small clumps are attractive in ponds, but extensive jungles of tules are of little use to waterfowl except for nesting cover and make waterfowl hunting nearly impossible. As such, they pose a serious threat in shallow ponds with fresh or slightly brackish water.

OLNEY BULRUSH

Olney bulrush (Scirpus Olneyi) is a perennial, triangular stemmed, sod-forming marsh plant with a very tight, fibrous root system. It reaches its highest development on highly organic soils that remain flooded to a shallow depth the year around. It probably is one of the last true marsh plants to dominate a freshwater marsh site before the meadow plants such as sedges, spikerushes and grasses take over the successional evolution of a marsh at this latitude. It is only moderately salt tolerant. Mall (1969) found that dominant stands had a mean annual salinity range of 8.5 to 20.7 0/00 (13.0 to 34.0 mmhos E.C.) and that the plant lost much of its competitive ability at salinities above 22 0/00 (33.0 mmhos E.C.). It produces very little seed and its major value to ducks is nesting cover. It is a valuable plant for muskrats (Joanen and Glasgow, 1965). Geese feed on the roots and tender shoots occasionally.

BALTIC RUSH

Baltic rush (Juncus balticus) is another sod-forming perennial that generally grows on a slightly drier site than Olney bulrush (Mall, 1969, and Chapman, 1960). It appears generally to be more of a meadow plant than a true marsh plant. It has a very small seed, and has little or no value as a duck food. The stems are generally too tough for geese to use so its main value is nesting cover. At best it is only moderately tolerant of salt. Mall (op. cit.) found it to be the least salt tolerant of the eight species studied in his survey of the Marsh. It is slow to invade new areas, but once established, it spreads vegetatively and tends to dominate the site, eliminating more desirable plants. It will tolerate moderate to heavy grazing.

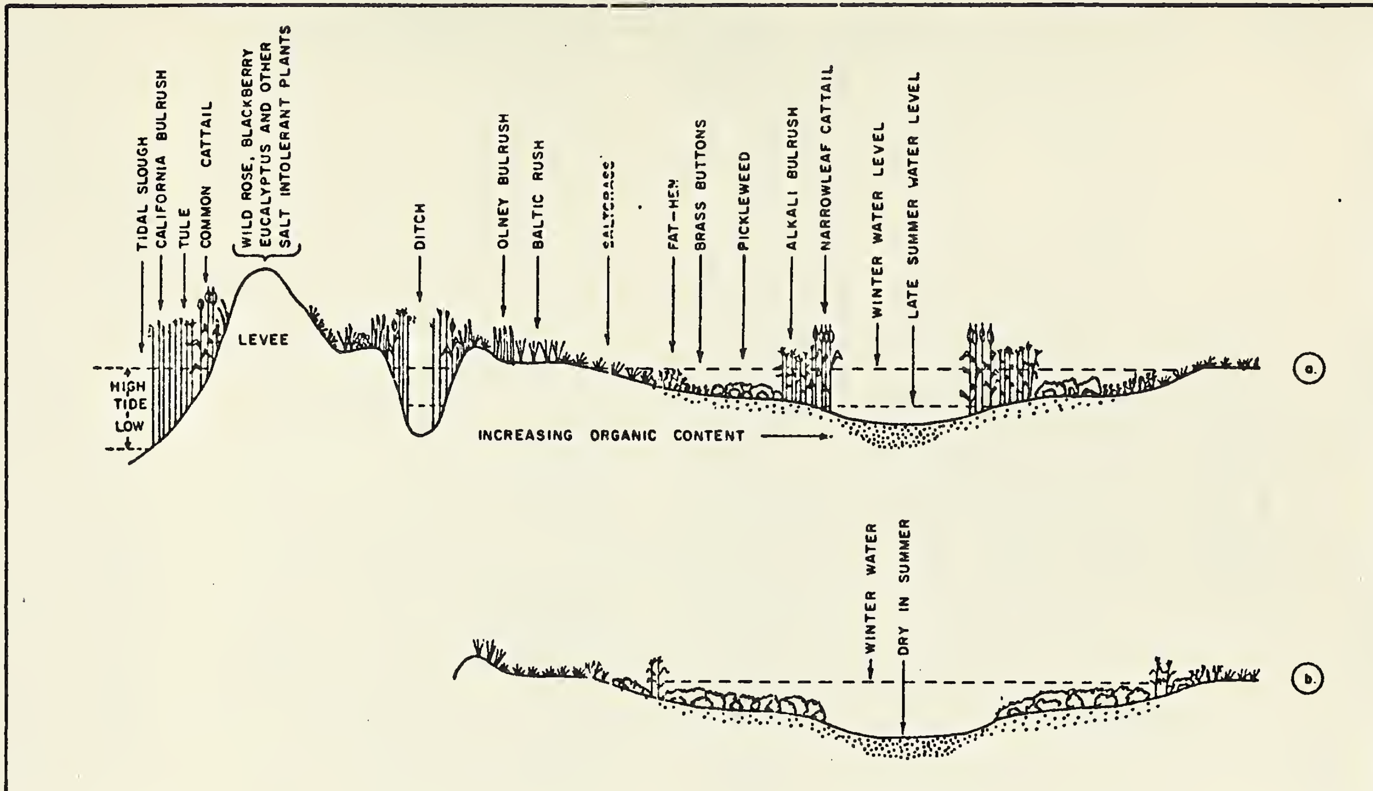
SALTGRASS

Saltgrass (Distichlis spicata) is a perennial sod-forming grass that is quite salt tolerant (Mall, 1969, Chapman, 1960, and Nelson, 1954). Mall (op. cit.) found it to be most competitive on soils with mean annual salinity of 33 0/00 (49.5 mmhos E.C.). The plant will tolerate shallow water (less than six inches - Mall, 1969) for brief periods but not total submergence. Therefore, it is found mainly on higher ground in the ponds. It appears to be intolerant of extended periods of flooding during the summer. The seed is eaten by waterfowl, particularly by shovelers (Mall, 1969) but it only produces a few pounds of seed per acre. Saltgrass tolerates moderate to heavy grazing.

PICKLEWEED

The common pickleweed (Salicornia virginica) is a suffruticose (woody at base and herbaceous above) perennial, and is a rhizomatous halophyte with fleshy stems. It makes up the most common cover type in the Marsh (George et. al., 1965, and George, 1974) and was ranked third in overall use by ducks, but had a very low overall selection value (Mall, 1969). It is an important food only to the American widgeon which eats both the seeds and stem fragments (Mall, op. cit. and George op. cit.). Arend (1966) considered pickleweed as an indicator of poor marsh management This plant obviously is salt tolerant. It and California cordgrass (Spartina foliosa) comprise the two dominant vegetational zones bordering San Francisco Bay proper (Pestrong, 1972). Mall (1969) found it to be the most salt tolerant of the eight plant species he studied (see Figure 1), tolerating salinities up to 81 0/00 (121.5 mmhos E.C.) and exerting competitive dominance over other plants at salinities above 11 0/00 (46.5 mmhos E.C.). Around the tidal zone of the San Francisco Bay it occurs in the upper part of the Marsh, growing higher than 8.4 feet above mean lower low water (Pestrong, op. cit.). In the Suisun Marsh, Mall (op. cit. page 28) found it growing . . . "over a wide range of elevations and was the most abundant member of the lower marsh flora. Most frequently, it was found in two situations: (1) near the lowest elevations of ponds that were drained early in the season, or (2) in narrower bands of vegetation at the edge of ponds that contained water for longer periods of time." (Figure 2). Pestrong (op. cit. p. 32) states: "Salicornia, however, lacks air storage tissue, and, as a result, seems to be unable to endure the longest periods of submergence Spartina experiences at the lower levels." Hinde (1954), as noted by Mall (op. cit.), observed this characteristic also. Under the first condition described by Mall (op. cit.) pickleweed is flooded only during the fall and winter when the plant apparently goes dormant. Presumably, this enables it to tolerate this degree of submergence. Mall's (op. cit.) further observations tend to confirm this: "Prolonged soil submergence reduced the competitive ability of pickleweed mainly by delaying growth." And, "Another pickleweed stand wilted when it was flooded during late summer after growing on unsubmerged soil for several months." This plant can be controlled or eliminated by extended periods of

FIGURE 2



Schematic representation of plant distribution in the Suisun Marsh in relation to two kinds of water management: (a) maintenance of pond water into early summer and (b) early spring water removal.

From Mall (1969) Soil-water-salt relationships of waterfowl food plants in the Suisun Marsh of California. Page 27.

flooding during the summer growing season. However, it might be necessary to maintain a water depth of more than five inches.

CALIFORNIA CORDGRASS

California cordgrass (*Spartina foliosa*) does not occur in the Suisun Marsh at this time, but it probably will in the future. It has invaded the tide flats of San Francisco Bay north of the Golden Gate during the past 20 years. In 1973 it was found growing as far east as Benicia on the north side of the Carquinez Straits; however, it had not invaded the south shore of the strait at Martinez. Along the north shore of San Pablo Bay it has replaced the stands of alkali bulrush that formerly occurred there, particularly at the mouth of the Petaluma River and Sonoma Creek.

This plant is a halophytic perennial grass with extensive creeping rhyzomes. It has a hard seed and is not a valuable duck food plant. Cordgrass tolerates salinities of 35 0/00 (sea strength) and has been grown in fresh water under laboratory conditions (Phleger, 1971 and Mason, 1973). Pestrong (1972) found the plant growing in the tidal range of 5.4 to 10.4 feet above MLLW (mean lower low water). At lower elevations the canes may grow up to 40 inches in height. It withstands frequent tidal inundation and endures as much as 21 hours of continual submergence.

SAGO PONDWEED

Sago pondweed (*Potamogeton pectinatus*) is a wholly submerged, aquatic plant, and considered a perennial because it produces fleshy winter corms. It grows in the permanently flooded ponds, ditches and channels in the Marsh and is a choice waterfowl food plant. All parts of the plant are eaten (McAtee, 1939). Browning (George, et. al., 1965) found all species of ducks using it, particularly mallard and pintail early in the season. The tubers are a choice food of canvasback. It grows in shallow water (one to six feet deep) and tolerates salinities up to 9.5 0/00 (14.2 mmhos E.C. - Leach, 1960). Carp also feed on the plant, often severly damaging stands to the detriment of waterfowl.

WIDGEONGRASS

Widgeongrass (*Ruppia maritima*) is a wholly submersed, aquatic herb that grows well in brackish water. It occurs in the permanently flooded ponds and ditches in the Marsh and is a choice food of waterfowl. The seeds, foliage and rootstocks are eaten (McAtee, 1939). Browning (George, et. al., 1965) found all waterfowl species sampled utilizing this plant to some extent. It grows well in the salinity range of 5 to 24 0/00 (7.5 to 31.0 mmhos E.C.) and has been reported as tolerating salinities up to 45 0/00 (67.5 mmhos E.C. - Simmons, 1957). Neely, (1962) recorded its salinity range as 12 to 35 0/00 (1.8 to 52.5 mmhos E.C.); Joanen and Glasgow (1965) found that widgeongrass attained maximum growth in a salinity range of 4.2 to 18.5 0/00 (6.3 to 27.0 mmhos E.C.).

MARSH MANAGEMENT

The control of water on the marshland afforded by the construction of levees and tidegates is the paramount factor affecting the Marsh environment. Essentially the character of the Marsh habitat is determined by water management. The quality of water applied is important, as well as the amount applied, when it is applied, for how long, and how deep. All of these must be taken into consideration. There are two basic patterns of water management used in the Suisun Marsh to produce waterfowl habitat - permanently flooded and seasonally flooded ponds.

PERMANENTLY FLOODED PONDS

As previously mentioned, a few areas of the Marsh were reflooded permanently following the construction of levees. Some duck clubs have operated their ponds with a more or less stabilized water level and continually circulating water for more than 40 years. In most cases the ponds have remained flooded continually except for periods when levee repair and other maintenance required the ponds to be dry. This period of relatively stable conditions has permitted the normal successional development of dense stands of emergent aquatics. Open water is restricted to the deeper portions of the ponds and channels, with water deeper than two feet, which is commonly vegetated with sago pondweed and widgeongrass. This open water is ringed with well developed stands of cattails and tules that have built up a considerable layer of dead plant material. In places, the peat has built up enough for Olney bulrush to become established.

Shallow water areas, away from the main channels and open water areas, have tended to develop high salinities because of the lack of effective water circulation resulting from blockage by heavy stands of vegetation. In such areas, stands of alkali bulrush, saltgrass and pickleweed have developed. In a few isolated spots, the salinity has built up above the tolerance of these plants and small bare "salt-flats" exist.

In these permanently flooded ponds with circulating water, the depth of water and salinity have strongly influenced the composition of the plant community.

SEASONALLY FLOODED PONDS

Most of the duck clubs are managed on a seasonally flooded pattern, i.e., flooded during the fall and winter for the waterfowl hunting season then drained in the spring and kept dry during the summer. On these clubs, vegetative development in the ponds differs from that found on permanently flooded ponds. In general, the same species occur but in different combinations, less dense and not as tall.

Mall (1969) concluded that length of soil submergence had the greatest influence on the distribution of Suisun Marsh plants. This is understandable with reference to seasonally flooded ponds. Chapman (1960) and others working with brackish water marshes have reported that salinity was the most important factor influencing plant distribution. However, they generally have worked with natural tidal marshes having a summer rainfall pattern. Where ponds are flooded during the fall and winter and dry during the summer, the length of submergence can have an overriding effect. Salinity has the same effect on plants as does drought. During dry summer periods without rainfall, the hydrophytic marsh plants are subjected to the combined effect of both. Therefore, the longer the time the soil is submerged, the shorter the period of stress for these hydrophytes. Conversely, for the plants that are not true hydrophytes, the shorter the period of soil submergence the better their competitive advantage. The successful plants are those that can tolerate both environmental conditions. Pickleweed, saltgrass and Baltic rush are good examples.

Switching from wet to dry soil conditions semi-annually tends to retard successional development toward a dominant perennial cover. Thus it is possible for annuals, such as fat hen and the shortlived perennial brass buttons, to maintain their position in the Marsh for a longer period. Seasonal flooding also tends to mask or reduce the effect that depth of flooding normally has on the species composition in a marsh. Plants that cannot tolerate continual flooding are able to survive inundation during the dormant winter period.

Experience with seasonally flooded ponds, backed by the research conducted by Mall (1969) and Rollins (1973), indicates that maintaining water in the ponds until June 1 each year (extending the duration of soil submergence) increases the yield of alkali bulrush. Observation of alkali bulrush stands during the past fifteen years, particularly on the Gum Tree Farm duck club, indicates that dry conditions in the ponds after June 1 tend to discourage the invasion of cattails and tules, thus helping to perpetuate this desirable species.

Thus environmental conditions that have existed in the seasonally flooded ponds during the past 40 years as a result of water management have tended to slow down the successional development of the marsh vegetation, resulting in less sedimentation, less production of vegetation and more oxidation of plant material.

SALINITY CONTROL

The gross effect of extreme salt concentrations is readily observable around Great Salt Lake and when sea water inundates a freshwater marsh. However, the effects of low to moderate salinities (oligohaline and mesohaline) are not so obvious. The research conducted by Mall (1969) and Rollins (1973) dealt directly with this problem in the Suisun Marsh.

Levees and tidegates that provide a means of controlling the water level within the enclosed ponds of the Marsh also impose the necessity of salinity management when brackish water is used. Otherwise, salinity will continue to build up and destroy desirable vegetation. The soil survey of the Marsh and work by Mall and Rollins (op. cit.) indicate that soil deeper than one foot has a high salt content and acts as a salt bank. Capillary action and hydrostatic pressure bring water to the surface of the soil to replace water lost to evaporation or transpiration and coincidently withdraw salt from this "bank" and deposit it at the surface. This occurs in seasonally flooded ponds, and the salt must be leached or flushed out annually to maintain a favorable salt balance in the soil. Add to this the salt load contained in brackish tidal water that is used to flood the ponds to maintain a stable water level, and the need for salt management becomes obvious.

Under present water quality conditions in Suisun Bay it is possible to maintain a stable salt balance by (1) adjusting the tidegates so that an adequate amount of water circulates through the flooded ponds during the winter, and (2) draining and flushing the ponds during late winter and early spring when the tidal waters are freshest.

In permanently flooded ponds enough water must be circulated through the ponds to carry off salt left by water which evaporates or is transpired by the plants. If this is not done, the ponds act as salt collection ponds. The same is basically true for seaonally flooded ponds except that salinization progresses more slowly. These ponds are flooded during the cool, wet part of the year when evaporation is quite low and most of the marsh plants are dormant. However, the effect on vegetation of any salt buildup in the soil is compounded in spring and summer as the soil begins to dry. Theoretically, soil with a moisture content of 200 percent and a salinity of 10 0/00 (15.0 mmhos E.C.) will have a soil moisture salinity of 20 0/00 (30.0 mmhos E.C.) when dried to the point where it has only 100 percent moisture content. Under actual conditions (Mall, 1969: Figure 5 with composited data) soil sampled in January had soil moisture content of 200 percent with a salinity of 20 0/00 (30.0 mmhos E.C.), while the following August the same soil had a salinity of 50 0/00 (75.0 mmhos E.C.) with a soil moisture percentage of 110 percent. The additional salt had come from the salt bank in the subsoil, with the water brought to the surface by capillary action. At 20 0/00 (30.0 mmhos E.C.) salinity and 200 percent moisture content in the root zone, most marsh plants could grow. While under the dryer condition, only the most salt-tolerant plants could be actively growing.

This interacting relationship between soil moisture content and salt content, and its effect on plant growth is a very important one to understand when working with a brackish marsh. It helps explain why the length of time that the soil is submerged is so important in seasonally flooded ponds and why alkali bulrush produces a better seed crop if the soil remains wet until June 1 (Mall, op. cit.).

Three other important concepts must be understood and remembered in dealing with salt management in the Marsh.

1) Even though rainfall helps some with salinity control, it is virtually impossible to reduce the salt concentration in the soil below that of the water which is available for leaching and flushing the ponds.

2) The higher the salinity of the water that is available for leaching and flushing the longer the time required to carry off a given amount of salt. Actually, leaching efficiency in the marsh is very poor because the natural water table is near or at the surface of the soil. Under such conditions the downward movement of water is very limited, depending largely upon the difference in the hydrostatic head between the pond level when flooded and the average level outside the pond. The result is that the concentration of salt in the pond water tends to equalize with that of the water in the soil (soil moisture) by diffussion and the salt is carried out of the ponds with the circulating water. Therefore, the smaller the difference between the salinity of the pond water and that of the soil moisture the slower the rate of diffusion. When no difference exists no diffusion takes place. The practical result of an increase in salinity of the water available for leaching during winter would be to lengthen the period of soil submergence. If salinity increased enough it would necessitate leaving the ponds flooded year around with continually circulating water to maintain a stable salt concentration at the lowest level possible. Permanently flooded ponds of this nature would result in a substantial change in plant composition.

3) Salinity can be used as a marsh management tool as long as the concentrations of salt in the ponds can be manipulated within the tolerance of the desired marsh plants (Soil Conserva-

tion Service, 1966). This requires a water supply with a salinity level below the upper tolerance limit of the desired plant species and close monitoring and control of water salinity in the ponds. Pond salinity can be increased to an optimum level for dominant stands of desired plants and held stable at that level. This discourages less tolerant species. Also, salt concentrations can be increased in the pond by controlling the outlet to where the salinity exceeds the tolerance of the undesirable species, then reduced to where the desired species can be reestablished. This type of management can be used effectively to encourage alkali bulrush in Suisun Marsh under present conditions.

If fresh water (less than 0.9 0/00) were used to flood the Marsh instead of the present brackish water, salts in the soil could be gradually reduced (see section on Projected Conditions). This would favor the less salt-tolerant hydrophytes to the detriment of halophytes such as pickleweed. Under the fresher condition, it would be possible to grow such moderately salt-tolerant waterfowl food plants as Japanese millet (Echinochloa crus-galli var. frumentacea), barnyardgrass (watergrass) and smartweed. However, the perennials such as cattail, tules, Olney bulrush, Baltic rush, and the common reed (Phragmites communis) would soon assume dominance if no corrective measures were taken. It would be necessary to keep the ponds flooded to a depth beyond the tolerance of cattail and tules or drain the ponds shortly after the hunting season and keep them drained the rest of the year. This would allow the soil to become dry enough to slow down the development of these plants. Under the latter condition, farm equipment would have to be used periodically to control the cattail and tules. This is done on waterfowl management areas in the Central Valley to perpetuate stands of barnyardgrass (watergrass) and the smartweeds (Miller and Arend, 1960, and Ermakoff, 1968). The high water table in the Marsh would make it very difficult to sufficiently dry soils, at lower elevations in the ponds, and to desiccate tules and cattail with summer drought alone. At present salinities, this can usually be accomplished in one summer without using farm equipment.

USE OF FIRE

Fire is a marsh management tool which reduces the accumulation of vegetation and the formation of peat. It seldom kills the marsh vegetation if the soil is saturated. Dry peat burns readily and a peat fire is difficult to control except by total submergence. Peat levees are particularly vulnerable because the freeboard area tends to dry out and often, cannot be submerged. Linde (1969) discussed the use of peat fires in Wisconsin to increase pond depths and the practice has been used here. Fire in Suisun

Marsh generally is used during late winter or spring to burn dead vegetation while the soil and levees are still damp and before waterfowl nesting begins. It also is used again in the fall just prior to the hunting season.

Marsh plants characteristically produce a large volume of vegetation that tends to break down slowly. In a brackish marsh, the decay progresses even more slowly because salt acts as a preservative. The accumulation of vegetation is overwhelming unless periodically burned. This is important in tidal areas where the accumulation of vegetation blocks drainage channels creating temporary pools suitable for mosquito habitat. The burning of saltgrass in the fall also improves these stands for goose pasturage and for livestock grazing. In addition, fire can be used to clear cattails and other vegetation from seasonally flooded ponds prior to the hunting season and can be used to destroy plant debris prior to preparing a seedbed.

GRAZING

Limited grazing in Suisun Marsh has occurred for some time (Arend, 1966). A small acreage of tidal marsh is grazed adjacent to Cutoff Slough, but most grazing is done within the leveed portions of the Marsh. A prerequisite to marshland grazing is a soil surface firm enough to support livestock. The Valdez clays are the most suitable for this land use. Some of the Marsh is used exclusively for grazing; however, most grazing is done in conjunction with waterfowl hunting either as a primary or secondary land use. In either case, it can be used (1) as a supplementary source of income to defray development and maintenance costs, or (2) as a marsh management tool. The management of grazing on marshland in Louisiana is outlined in detail in the Louisiana Gulf Coast Marsh Handbook (SCS, 1966).

The primary effect of grazing is the utilization of plant material and subsequent reduction in the accumulation of peat. As a secondary effect grazing influences plant composition. Grazing animals are selective, taking the most palatable plants. This gives the less palatable plants competitive advantage. Alkali bulrush, both a good waterfowl food plant and a palatable plant for cattle, is seldom found on intensively grazed areas because livestock tend to overgraze it. Also, the plant species that are more typically meadow plants, saltgrass and Baltic rush, are usually more resistant to grazing damage and are better adapted to drier environmental conditions needed for grazing animals. Thus these plants tend to predominate where grazing occurs regularly. The rank growth of cattail and tules are not particularly palatable to cattle. These plants tend to occur in the wetter areas along ditches and sloughs, and in poorly drained areas.

Here they are relatively unavailable to livestock until late in the season when they are the least palatable. The result is that grazing is of limited use as a tool in controlling excessive stands of tules and cattails. Grazing should be closely managed under a rotation or deferred grazing system so as to accomplish the reduction of vegetative growth and still protect choice waterfowl food plants.

MOWING

Mowing is used to control excessive standing vegetation around blinds prior to the hunting season. It is usually done late in the summer in seasonally flooded ponds when most of the vegetation is mature or dormant. Thus, it has little lasting effect on the vegetation, particularly in shallow ponds.

In deeper ponds the cutting of marsh vegetation (cattails and tules) below the water line seriously affects the plants by depriving the roots of their main source of oxygen (Linde, 1969). Unless some of the stems of cattail and tules protrude above the water to translocate oxygen to the roots the survival of the plant is in jeopardy. The greatest limitation on the use of mowing for cattail control is the difficulty and expense involved in operating mechanical cutters in flooded ponds.

CULTIVATION AND PLANTING

Cultivation of marshland soils to control unwanted vegetation and to prepare a seedbed for planting crops such as barley and oats has been done on Grizzly Island and around the edge of the Marsh for many years. Cultivation can be used to retard or reverse plant succession in the Marsh by breaking up dominant stands of perennials and returning the soil to a "bare ground" state where seed producing annuals can re-invade or be planted. However, like grazing and mowing, a prerequisite is a soil surface firm enough to support heavy equipment. The ponds must be drained and the soil allowed to dry out considerably to accomplish this.

Mineral soils such as Valdez silty clay loam will support equipment more readily than the muck or peat soils. The lower portions of ponds with muck soils (Suisun series) may be nearly impossible to cultivate because of their high moisture content, over 400 percent in some cases (Mall, 1969), and the difficulty encountered in attempting to lower the water table sufficiently to allow the soil profile to dry.

The thicker the thatch and denser the sod the heavier the equipment required to accomplish marshland cultivation. Heavy-duty discs and plows must be used with large tractors. The dense sod must be re-worked several times to break up the clumps sufficently to kill the plants and to prepare a seed bed. Stands of pickleweed usually can be broken up more easily than stands of cattail, tule or Olney bulrush.

As mentioned earlier, barley has been the main crop planted in the area for waterfowl use. However, oats, Japanese millet and alkali bulrush have been planted successfully. Barley and oats are not hydrophytes and will not grow under flooded conditions. Although the normal planting time for barley is in the fall, the duck clubs, which attempt its use, delay planting until spring time. The ponds are drained when the hunting season is over and planting is done as soon as equipment can be used. Under present conditions, the practice is marginal because (1) no allowance is made for extra flushings to reduce the salt load and (2) it requires ideal weather for success. On the Grizzly Island Wildlife Management Area, barley is planted in the fall on soil that is not normally flooded. Geese graze the young plants during the winter. The crop matures in the late spring and stands until the following fall and winter when the seed is utilized. A crop is planted every other year or every third year if one volunteer crop is produced.

Japanese millet is a warm-season grower and must be planted in the late spring or early summer. It requires water during the summer to mature and usually the water available at this time is too saline for this plant. For this reason only one or two plantings have been successful. With fresher water (less than 3 0/00 or 4.5 mmhos E.C.) this plant could be planted regularly using cultural methods described by Miller and Arend (1960) and Ermakoff (1968) for the Central Valley of California.

Alkali bulrush has been seeded into ponds devoid of vegetation and in ponds that have been renovated by cultivation. The method for such plantings has been described by George (1963) in "Game Management Leaflet #9" and by O'Neill (1972).

HERBICIDES

Herbicides have not been used extensively in the Suisun Marsh as a management tool to control vegetation. In general the cost of application has been too high for the short-lived results. Better results are obtainable by draining the ponds and letting drought and high soil salinity desiccate the marsh vegetation. If the Marsh were to become more nearly a fresh water marsh, the use of herbicides might be necessary to control unwanted vegetation. Linde (1969) and Nelson and Dietz (1966), have described the use of herbicides in the control of marsh vegetation.

MUSKRATS

Muskrats feed on marsh vegetation and use it to build houses. Where heavy muskrat populations have been allowed to develop, they have had a dramatic effect on marsh vegetation. Many descriptions of muskrat "eat outs" appear in the literature. However, in the Suisun Marsh where levees are so vulnerable to muskrat damage, their population cannot be allowed to increase to such densities. They remain as a nuisance rather than a potential marsh management tool.

CARP

The sloughs and permanently flooded ponds of the Marsh provide habitat for the common carp. Carp are bottom feeders and they compete with waterfowl for food in permanently flooded ponds. They feed on the roots and tubers of such plants as sago pondweed and widgeongrass, as well as benthic organisms. In searching the mud for food, carp stir up the bottom sediments increasing turbidity in the ponds. In permanently flooded ponds, they can become so numerous that they eliminate the growth of sago pondweed.

Although control of carp in seasonally flooded ponds is no problem, it is difficult to achieve in permanently flooded ponds. The striped bass is a natural predator, but in shallow ponds with an abundance of emergent vegetation, the small carp have ample protection. They soon grow beyond the size vulnerable to bass predation.

Carp can be killed with rotenone or antimycin, but it is doubtful if this is a practical solution under existing conditions. At best it would produce only temporary results. The large volume of water that must be circulated through a pond to obtain salinity control and the amount of debris in the tidal water makes effective screening of the inlets and outlets impractical. A partial solution developed in cooperation with the Joice Island Gun Club is to drain the ponds completely for a short time during the winter and then re-flood them. This forces the carp to leave the ponds and it appears that most of them do not find their way back into the ponds with the new flood water. Carp still come into the ponds as the tidegates operate, but the annual winter drain cycle seems to reduce the concentration of carp and the damage they do to the sago pondweed.

MOSQUITO ABATEMENT

No one who has been in the Marsh for long will deny that mosquitos are part of that environment and few will argue with the concept that all reasonable abatement measures should be taken.

Mosquitoes, which are unique creatures common to all marshes, have evolved tolerances to a wide variety of environmental conditions. In spite of the variation and diversity in the more than 4,000 species, they all pass through larval and pupal stages confined to water (Bickley, 1959). Mosquito larvae survive most successfully in shallow ponded water where their natural predators do not have a favorable environment. Mats of dense vegetation in shallow water also afford protective cover for mosquito larvae. Another factor influencing their survival is water temperature. Mosquitoes go through their development stages from egg to adult much more rapidly in warm water (up to about 90°F. - Bickley, 1959). Under optimum conditions they can reach the adult stage in five days and thus they have the potential to increase explosively. In cold water it may take three or four weeks for an egg to reach the adult stage. Fewer generations are produced and the larvae are exposed to predation and other mortality factors for a longer period of time. Predation by fish is much more effective in open water. Also, water currents and wave action tend to upset the movement of larvae to the surface for oxygen and thus induce mortality.

The "pasture" mosquito is the most troublesome of the five species found in the Marsh. These mosquitoes lay their eggs singly on the ground, on the sides of duck blinds or on similar sites and depend on fluctuating water levels or re-flooding to induce hatching. The larvae can live in fresh or very brackish water. The adults are capable of migrating in excess of 20 miles (Loomis, 1967) so they are a threat to nearby communities.

The encephalitis mosquito is the second most troublesome mosquito in the Marsh. They lay their eggs in masses (rafts) on the water where the eggs float until hatching occurs. They are strong fliers and bite man and birds as well as livestock.

Mosquito abatement measures have been developed over the years in the Suisun Marsh with these factors in mind. In general, the following measures apply to the leveed portions of the Marsh: (1) no water levels are allowed to fluctuate after April 1, (2) all ponds should be draining by June 1 - except permanently flooded ponds that have stabilized, circulating water, and (3) no flooding of ponds in the fall before October 1 or no more than three weeks prior to the duck hunting season. The main object is to prevent conditions conducive for mosquito production during the warmer part of the year.

As mentioned earlier, vegetation growing in shallow water tends to protect mosquito larvae from predators and, according to Mr. Mezger, Manager, Solano County Mosquito Abatement District, flooded saltgrass and pickleweed stands provide the best mosquito habitat. If there are any mosquito larvae in the pond most probably they will be found in these two cover types.

Mosquitofish are used extensively to control mosquitoes. These small topminnows tolerate brackish water up to 20 0/00 and can survive in very shallow water. They are usually found throughout the Marsh and can be transplanted into new ponds if necessary. All small fish, regardless of the species, tend to eat mosquito larvae but mosquitofish are particularly useful for this purpose.

If ponds are inadvertantly flooded during the summer, it is usually necessary to apply insecticides to control mosquitoes.

OTHER FACTORS

To attract and hold a huntable population of waterfowl, a duck club area must provide an adequate supply of food and suitable cover as well as water. Ducks and geese, particularly pintails, are reluctant to alight in dense vegetation. They prefer to land in open water where they feel secure and then swim into the vegetation to feed. This has been found to be the case even when they feed in commercial rice fields. Depredation problems develop first in rice paddys with potholes or poor stands. Food is important but the ducks will seldom decoy into a dense stand of food plants during the hunting season. They will raft up in open water and come into feed after dark if necessary. Thus the duck hunter who provides a "duck cafeteria" by filling his ponds completely with food plants will usually be quite disappointed in hunting quality. Such disillusioned hunters often conclude that open water and no feed is better than attempting to provide too much feed. A reasonable balance of emergent food plants and open water is desirable.

Likewise, to many people, extensive stands of cattail, tule and Olney bulrush appear to provide ideal habitat for ducks. Actually it is hazardous for ducks to enter such a jungle. They are quite vulnerable to predation by otters and mink where heavy vegetation impedes their ability to take flight. To the hunter who has to make his way through such jungles to get to his blind or to find his birds or catch a cripple, they are far from ideal. Also, ducks must be able to see the decoys before they will decoy into a pond. A few clumps are attractive and add diversity to the duck pond, but it is difficult to keep them from eventually taking over the whole pond. A balance of cover plants, food and open water is the ideal condition - not a so-called "climax marsh."

Habitat management costs must be kept within reason. If the costs of management are too high, the necessary management too difficult or the returns to management too low, club owners will abandon the enterprise with a subsequent decrease in suitable waterfowl habitat.

When dealing with any problem, the tendency is to look at it from a single view point. For simplicity, this is logical. However, few resource problems are simple enough to deal with satisfactorily with a single-minded approach. Marsh management is no exception. A plant ecologist might like to watch the Marsh develop successionally with as little outside interference or management as possible. Some waterfowl managers would like to turn it into one big "duck cafeteria." Some duck hunters might wish to develop it as a natural "flighted mallard" operation. While individual areas can be managed with a single-purpose objective, a successful management plan for the Marsh must be a reasonable blending of these objectives.

REQUIREMENTS OF OTHER WILDLIFE

While the Marsh is maintained primarily for waterfowl habitat and recreational hunting and fishing, the requirements of other species of wildlife must be kept in mind. Pheasants are an important upland game species that occur around the margin of the Marsh and on Grizzly Island. However, the population levels are generally quite low (Griffith, 1963).

Good pheasant populations are usually found where there is some grain production, sufficient fresh water and adequate cover to satisfy their needs. Grizzly Island Wildlife Management Area with its barley production, ditches and ditch bank cover appear to fulfill these requirements. However, it has a low-density pheasant population (Griffith, op. cit.). Griffith and others questioned the quality of the drinking water that was available. A search of the literature showed that pheasants as well as ducklings were susceptible to salt poisoning at concentrations well below those often found in sloughs and drains of the Marsh during summer. Temporary watering devices were put out in pheasant habitat on the Grizzly Island Wildlife Management Area and Griffith (personal communication) reported that observations showed pheasants congregated around them and used them regularly while they were available.

In view of the foregoing it would appear advisable to supply supplemental fresh water under present water quality conditions if a good pheasant population is to be maintained. With degraded water quality conditions it is doubtful any pheasants would survive without supplemental fresh water.

The Marsh supports populations of water birds such as herons, egrets, rails, terns and gulls. Presumably, these would not be seriously affected by an increase in the salt content of the water in the Marsh since they also frequent the tidal marshes along the coast. The same is probably true for the white-tailed kites and other raptors which obtain most of their water from the prey they eat. Little is known of the water requirements of passerine marsh birds to form a basis for a judgement except to say that if the salinity increased enough to effect a change in the plant cover it would surely affect them also. The same can be said for the river otter, mink, raccoon and other small mammals occurring in the Marsh.

Two endangered species, the salt marsh harvest mouse and the California clapper rail, and one rare species, the California black rail probably occur in the Marsh (Leach, Brode and Nicola, 1974). It would appear that these species can tolerate the more saline waters around San Francisco Bay and the coast; therefore, as long as marsh conditions are maintained these species could survive even if water salinity increased. The maintenance of good waterfowl habitat in the Marsh is important indirectly to the southern bald eagle and American peregrine falcon (duck hawk).

COLLECTION OF DATA

A soil survey of Suisun Marsh was completed in 1965 by SCS and was summarized for use as basic inventory data in the prepara- of this marsh management plan. Other field studies were conducted in the Suisun Marsh during 1972-73. These studies included:

1. Monitoring the salinity and pH of soil and water at selected locations in the Marsh to determine salinity and pH gradients.
2. A survey of conditions found on private duck clubs and an inventory of water control facilities in use.
3. Sampling marsh plants to determine waterfowl food production potential.
4. Monitoring time required to flood the ponds to the level desired during the hunting season and the time necessary to drain them.
5. Determining the elevation of water control structures in relation to tide stages and average pond depth on a representative sample of duck clubs.

SOIL AND WATER SAMPLING

Water and soil salinities were monitored on five private duck clubs in the Suisun Marsh. The clubs studied were located in different areas of the Marsh so information could be obtained about the influence of location as it relates to source of water, on soil and water quality of the clubs. Two clubs located adjacent to each other were studied to evaluate two types of water management and the effect of water circulation. The five duck clubs on which these studies were made included:

1. B & O Sportsman Club - located on Denverton Slough near Bradmoor Island,

2. Gum Tree Farm - located on Grizzly Island (water circulates through club),
3. Paton Place - located adjacent to Gum Tree Farm (water is not circulated),
4. Montezuma Ranch - located at Montezuma Slough on Van Sickle Island (area of lower salinity water) and
5. Mulberry Land Company - located between Grizzly Bay and Goodyear Slough (area of higher salinity water).

Water sampling began on November 21, 1972 with subsequent samples being collected on or about the 20th of each month. Water samples were collected six inches below the water surface and placed in air tight plastic containers.

Soil samples were not obtained from ponds until the soil surface became exposed as the ponds were drained. The first soil samples were collected on May 23, 1973 and subsequent samples were obtained in conjunction with the water samples. Soil sampling was continued for the first two months after the ponds were flooded again in the fall. A soil auger was used to obtain soil samples at a depth of four to six inches below the soil surface. These samples were then placed in plastic bags and sealed.

The pH of the waters sampled was determined by using a field chemical kit developed by the Hach Chemical Company. The Bureau of Reclamation conducted the analysis of the water and soil samples in their laboratory in Sacramento, measuring electro-conductivity and soil pH.

Other parameters noted at the time of monthly field sampling included: Air and water temperatures, wind direction and velocity, cloudiness, stage and direction of tide flow and status of water in duck ponds. These data were used, within their limitations, to evaluate the effect of water source on club location and water management.

Additional soil samples were obtained on September 13, 1973 from three duck clubs previously studied by the California Department of Fish and Game (Rollins, 1973). The sample sites were located on the Shelldrake, Teal and Northend duck clubs. These samples were obtained in a similar manner to those by Rollins (1973) to determine if any significant change had occurred in the electro-conductivity and pH of the soil since the previous study was completed in 1968. The samples were analyzed by the Bureau of Reclamation.

Additional information on water quality was made available by the Bureau of Reclamation and California Department of Water Resources.

INVENTORIES OF PRIVATE DUCK CLUBS

Inventories were begun on private duck clubs in the Suisun

Marsh by the Soil Conservation Service on April 16, 1973. Subsequent to that date a private consultant, Kurt Kline, was employed through the Suisun Resource Conservation District to conduct a major portion of the duck club inventories.

Inventory forms (Appendix 1A) were developed to facilitate and insure the collection of similar data for all clubs. The information recorded on these forms were based on visual observations and communication with club owners, caretakers or others knowledgeable of the club's management and facilities. Maps were drawn of each club (scale of 1 inch = 660 feet) and were used to show location of water control structures, sloughs and ditches, and to delineate the areas of various types of vegetation on the club.

There are 144 duck clubs in the Suisun Marsh, of which 109 were inventoried. A duck club as used in this study was considered to be an area within a given levee system which utilizes the same water management facilities and practices regardless of the number of legal owners.

The criteria used for evaluating the condition of levees and ditches as well as results of seeding may be found in Appendix 1B.

An approximation of the percent composition of the various plant species found within the managed (leveed) areas of a club was obtained by visually estimating the percent of major plant species within delineated plant communities on a map. A planimeter was used to determine the size of the areas. The percent composition of the representative plants for a given duck club was determined from the sum of the areas.

Seventeen plant species or groups were used in the vegetation study (Table 6). Groupings were made of some plant species which were closely related, had similar habitat requirements or comprised only a small percentage of the total vegetation in the Suisun Marsh.

Correlation of vegetative composition data to management was made for vegetation found within the manageable portion of the duck clubs, i.e., within levees, excluding tidal land and major upland areas. The major upland areas excluded occurred almost entirely on clubs on the perimeter of the Marsh where a large portion of property was too high to be flooded using tidal waters. Here the vegetation was characterized by upland grasses and associated upland herbage.

MEASUREMENT OF FOOD PRODUCTION

Samples were obtained from eight species of plants which occur in the Suisun Marsh to determine the amount of food each produce as seed and/or "edible greens." The plants sampled included:

TABLE 6

PLANT SPECIES OR GROUPS* INVENTORIED
ON DUCK CLUBS IN SUISUN MARSH

1. Alkali bulrush	10. Sago pondweed
2. Baltic rush	11. Saltgrass
3. Barley	12. Thistle 2/
4. Brass buttons	13. Tule 3/
5. Cattail 1/	14. Wild radish (*Raphanus sativus*)
6. Dock (*Rumex sp.*)	15. Upland grasses 4/
7. Fat hen	16. Miscellaneous 5/
8. Olney bulrush	17. Bare ground
9. Pickleweed	

* Some plants were combined into groups:

1/ Cattail-- includes *Typha angustifolia*; *T. domingensis*; *T. glauca*; *T. latifolia*

2/ Thistle-- includes *Cirsium hydrophilum*; *Silybum marianum*; *Xanthium canadense*.

3/ Tule-- includes *Scirpus acutus*; *S. californicus*.

4/ Upland grasses-- includes *Lolium multiflorum*; *Avena fatua*; *Polypogon monspeliensis*.

5/ Miscellaneous-- includes *Spergularia marina*; *Polygonum aviculare*; *P. argyrocoleon*; *P. lapathifolium*.

1. Alkali bulrush
2. Tule
3. Olney bulrush
4. Baltic rush
5. Brass buttons
6. Fat hen
7. Pickleweed
8. Saltgrass

Samples were obtained by selectively throwing a wire frame, measuring 9.62 square feet, over an area which appeared to be a representative stand for the sampling location. The seed heads and/or edible greens were clipped off the plants within the ring and placed in labled paper bags. Brass buttons samples were obtained using a wire frame one foot square. The samples were allowed to dry and if possible, the seeds were separated using a "clipper" (model M-2B air screen) seed cleaner. The results were expanded by simple proportions to obtain the estimated pounds per acre produced.

Alkali bulrush was more intensively sampled than were the other species and used in correlating seed production to type of water management. Samples were collected on the five following duck clubs:

1. Whistling Wings - drained right after the season,
2. Garibaldi Brothers Duck Club - also drained right after the season,
3. Teal Duck Club - flooded all year (due to levee break),
4. Spoonbill Duck Club - located in a freshwater area, and
5. Gum Tree Farm - follows the approved water management program.

Five samples were taken on each club. The soil type, average plant height, and the plant's stage of maturity were also noted.

WATER CONTROL STUDIES

Information obtained from selected duck clubs was used in determining the time required for clubs to flood and drain and the volume of water on the ponds when flooded. This information was obtained by establishing elevations for various water control structures, determining average pond depth and monitoring flooding time.

On September 24, 1973, tide gauges were placed at the inlets of Gum Tree Farm, Montezuma Ranch, Mulberry Land Co., Paton Place, and Teal Duck Club. The gauges were checked the following day to establish elevations at inlet structures, utilizing the high tide level occurring the previous night. Using this information, along with inlet size and tidal fluctuation, the volume of water needed to flood ponds, and the time required to flood or drain ponds was computed.

A traverse survey was run across the pond on the Teal Duck Club. The elevations used were tied into that of the water control structure previously determined using the tide gauge. The average depth of the pond when flooded level 1/ was then determined.

In November 1973, depth soundings were made in transects across ponds on Gum Tree Farm, Mallard Inn Duck Club, Whistling Wings, Paton Place, Tule Bell Duck Club, and West Family Duck Club. This was done to obtain an approximation of the average depth of water on these clubs. These transects and the one on the Teal Duck Club were compared with average pond depth estimations made in the inventories of the private duck clubs to determine the average depth of ponds for the Marsh.

Forms were distributed to five duck clubs to obtain information on the time required to flood their ponds to shooting level. The five duck clubs included Gum Tree Farm, Montezuma Ranch, Mulberry Land Company, Paton Place and Teal Duck Club. The forms, completed during the fall of 1973, requested the time and date when flooding began and when shooting level was reached. Included on the form was a space to indicate departure from normal flooding schedule or other problems influencing flooding time.

PRESENTATION OF DATA

SOILS

Soils of the Suisun Marsh can differ one from the other within a very short distance (see soils map, plate 1, pocket inside cover). The differences result from interaction of five soil forming factors, namely: parent material, relief, climate, biological activity and time. The relative effect of each of these factors varies with each soil. Their influence on the processes of soil formation are more easily described by relating soils within areas of similar land forms. Suisun Marsh soils are associated with two distinct land forms, the Delta, and flood plains and natural levees.

DELTA

Delta soils are mixtures of hydrophytic plant remains and mineral sediments. The poorly drained environment produced a dense growth of tules and other hydrophytes. The organic remains from these plants accumulated over a long period of time. During this period, the underlying base material slowly subsided as the layer of peat thickened. Mineral sediments were added to the organic deposits by tidal action and deposition from turbid water

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1/ Shooting level is the common term for the level at which water is maintained for waterfowl hunting.

during floods or periods of large flows in the rivers. These soils vary from organic soils with a small amount of mineral matter (usually found as thin silt and clay lenses) to mineral soils with a low organic matter content. Generally the higher mineral content is associated with soils adjacent to sloughs and channels.

Soils of this land form include Suisun, Joice, Tamba and Reyes (Appendix 4). The Reyes series are mineral soils and occur adjacent to the sloughs where most of the mineral sediments were deposited in existing vegetation as high tides and flood water spread outward from the sloughs. Tamba soils occur adjacent to Reyes soils, farther from the sloughs, at a slightly lower elevation and have poorer drainage. Sediment deposits were reduced, resulting in a higher percentage of organic matter to mineral matter. Joice soils occur still farther from the sloughs at a slightly lower elevation. The mineral sediments were further reduced, resulting in still higher organic matter content. Suisun soils occur farthest from the sloughs at the lowest elevations, and have a small mineral content and high organic matter content.

Lowering the water table during the summer in seasonally flooded ponds has caused irreversible surface cracking and subsidence. (Photo 1). Also, soils formed in brackish water have an environment associated with production of "cat-clays" which are characterized by the formation of sulfuric acid and a reduction in pH during periods of summer drainage. This is particularly evident in the Reyes and Tamba soils.

FLOOD PLAINS AND NATURAL LEVEES

The alluvium deposited as natural levees and flood plain sediment occur as a narrow band primarily on Grizzly Island. The sediments are mineralogically heterogeneous as they originated from a variety of very recent deposits. Some date back to the days of hydraulic mining in the Sierra Nevada foothills when the river channels were choked with debris and sediment. The material was eventually translocated to the Delta and Suisun Marsh suspended in winter and spring runoff waters. The soils of this geomorphic unit include the Valdez series. Suisun Marsh soils, their soil characteristics, qualities and interpretive data can be found in Appendix 4.

LAND AND WATER AREAS

The Suisun Marsh, as mentioned earlier, is a complex of bays, channels, sloughs and marshlands (natural and controlled). Acreages were determined by type of ownership and land use for land areas within the Suisun Marsh (Table 7). The Marsh boundary was delineated as the outermost extension of typical marsh flora shown by infrared

Photo 1. Surface soil cracking due to drying of seasonally flooded soils.

TABLE 7

ACREAGES BY TYPE OF OWNERSHIP AND LAND USE
FOR THE SUBDIVISIONS OF SUISUN MARSH, 1973 *

			LAND USE				
Group	Total Acres	Wildlife Wetland	Wildlife Wetland and Pasture	Pasture	Cropland	Pheasant Club
			Private Land			
I	6,940	5,570	1,110	260	0	0
II	7,360	4,310	1,390	1,110	0	550
III	5,600	1,250	4,350	0	0	0
IV	3,340	3,340	0	0	0	0
V	14,490	10,360	3,330	580	220	0
VI	7,980	5,680	540	1,760	0	0
Total	45,710	30,510	10,720	3,710	220	550
			State and Federal Lands			
CFG	10,490	8,090	0	0	2,400	0
USN	1,110	1,110	0	0	0	0
			Total Suisun Marsh			
	57,310	39,710	10,720	3,710	2,620	550

* Acreages rounded to the nearest tens of acres.

photography (Frontispiece, courtesy of NASA & Ames Research Center, July 5, 1972).

The marshland area of Suisun Marsh comprises approximately 57,310 acres of which about 45,710 acres is privately owned, 10,490 acres is owned by the State of California and 1,110 acres is controlled by the U.S. Navy. Approximately 50,430 acres is used as wildlife wetlands; 10,720 acres of this is also used for grazing of livestock. The cropland is primarily limited to the Grizzly Island Wildlife Area where barley is grown on Valdez silty clay loam, primarily for consumption by geese. A private farming operation of nearly 220 acres commercially produces barley and oats. Four private duck clubs in Group I also grow barley for waterfowl use, but the total acreage is limited to less than 20 acres. Approximately 550 acres of marshland in Group II is used as part of a private pheasant club operation. Within Solano County, there are approximately 22,270 acres in bays. Channels and sloughs combine to form an additional 4,610 acres (George, Personal Communication, 1973). Because of technical limitations, some of these channels and sloughs were included as acreages in the marshland areas described above. Approximately 1,050 acres of non-tidal sloughs are found within leveed portions of duck clubs.

SUBDIVISIONS OF THE MARSH

Suisun Marsh was divided into six groups (Plate 2) based upon geographic location and primary water source. Using these criteria, it was possible to distinguish areas which more accurately reflect the natural conditions existing in the Marsh, and that influence its vegetation. Subdividing the Marsh in this manner also provides an organizational framework for physical data.

GROUP I

These duck clubs are located in the northwest portion of the Suisun Marsh. The tidal waters of Cordelia, Chadbourne, Wells and Suisun Sloughs and their distributaries provide water for these clubs.

This area receives freshwater runoff from watersheds of Suisun and Green Valley Creeks located northwest of Suisun Marsh. Seasonal runoff from irrigated cropland and orchards in these watersheds influence flow and water quality in this area. Water quality in Cordelia Slough is influenced to a small degree by the effluent from the Cordelia Wastewater Treatment Plant and by incidental discharge from the Putah South Canal.

The salinity levels of sloughs in this area average 12.0 mmhos E.C. (8.0 0/00) or less for the dry period of a normal year (Bureau of Reclamation, 1972) and 3.0 mmhos E.C. (2.0 0/00) or


PLATE 2
SUISUN MARSH SURVEY GROUPS
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA
AUGUST 1974
SCALE 1:135,000
0
2 MILES
SUISUN MARSH STUDY AREA
Study Area Boundary
Ownership Boundaries
Group Boundary
II Group Number
SOLANO COUNTY
Suisun Marsh Study Area
LOCATION MAP
SACRAMENTO CO.
CONTRA COSTA CO.
SOLANO CO.
POTRERO HILLS
Suisun Hill
Luco Hill
Kirby Hill
Meins Landing
Pierce Harbor
Fairfield
Suisun City
Cordelia
To Rio Vista
To Birds Landing
To Collinsville
To Benicia
GRIZZLY ISLAND
GRIZZLY BAY
HONKER BAY
SUISUN BAY
HAMMOND
WHEELER ISLAND
SIMMONS ISLAND
RYER ISLAND
MORROW ISLAND
VAN SICKLE ISLAND
CHIPPS ISLAND
JOICE ISLAND
MONTEZUMA SLOUGH
SUISUN SLOUGH
NURSE SLOUGH
SACRAMENTO RIVER
Roe Island
Freeman Island
Snag Island
Middle Ground Island
I
II
III
IV
V
VI

less during the wet period. In a dry year average salinities are 20.0 mmhos E.C. (13.3 0/00) and 6.0 mmhos E.C. (4.0 0/00) or less during dry and wet seasons respectively (Table 8, Plates 3 and 4, Bureau of Reclamation, 1972).

Soils of duck clubs in this area are relatively equal mixtures of Reyes silty clay, Tamba mucky clay and Joice muck (Plate 1).

GROUP II

This group includes clubs located in the north central portion of the Marsh. Suisun Slough and its distributaries provide water for clubs in this group. Effluents from Suisun, Fairfield and Travis Air Force Base Sewage Treatment facilities influence water quality. Ledgewood, McCoy and Union Creeks and runoff from the westerly drainage of the Potrero Hills flow seasonally into the area.

During a normal rainfall year the salinity levels of sloughs in this area average less than 12.0 mmhos E.C. and 3.0 mmhos E.C. (8.0 and 2.0 0/00) for the dry and wet periods respectively (Table 8, Plates 3 and 4). In a dry year the average salinities can be expected to range from 20.0 mmhos E.C. (13.3 0/00) or less for the dry periods to 6.0 mmhos E.C. (4.0 0/00) or less for the wet period.

Soils associated with duck clubs in this area are a combination of Joice muck, Suisun peaty muck, Tamba mucky clay, and Reyes silty clay in decreasing order of relative abundance (Plate 1).

GROUP III

Duck clubs in this group are found generally north and east of the Potrero Hills and Montezuma Slough (Plate 2). The tidal waters of Cross, Denverton and Nurse Sloughs and their distributaries provide water for management of clubs in this area.

Fresh water enters this area from the seasonal flows of Denverton Creek, westerly watersheds in the northern portion of Montezuma Hills, and easterly runoff from the Potrero Hills.

During a normal rainfall year, the salinity approaches 10.5 mmhos E.C. (7.0 0/00) during the dry period and 2.2 mmhos E.C. (1.5 0/00) in the wet period (Table 8, Plates 3 and 4). In a dry year, the salinities approach 18.0 mmhos E.C. (12.0 0/00) and 5.2 mmhos E.C. (3.5 0/00) respectively for the dry and wet periods.

The salinity of Denverton Slough was monitored at the B & O Sportsman Club, beginning in November 1972. The average salinity for the period of November 1972 through March 1973 was 3.1 mmhos E.C. (2.0 0/00) and 6.9 mmhos E.C. (4.6 0/00) for the period of

TABLE 8

THE AVERAGE SALINITIES OF WATERS USED TO FLOOD VARIOUS GROUPS OF DUCK CLUBS IN THE SUISUN MARSH IN MILLIMHOS ELECTRICAL CONDUCIVITY

	Normal Year 1/		Dry Year 1/		Denverton Slough		Suisun Bay		N.S. Montezuma Slough		S.E. Montezuma Slough	
Group	Wet Period	Dry Period	Wet Period	Dry Period	Wet Period	Dry Period	Wet Period	Dry Period	Wet Period	Dry Period	Wet Period	Dry Period
I	Less than 3.0 (2 0/00)	Less than 12.0 (8 0/00)	Less than 6.0 (4 0/00)	Less than 19.5 (13 0/00)								
II	Less than 3.0 (2 0/00)	Less than 12.0 (8 0/00)	Less than 6.0 (4 ø/00)	Less than 19.5 (13 0/00)								
III	Less than 1.5 (1 0/00)	Less than 10.5 (7 0/00)	Less than 5.2 (3.5 0/00)	Less than 18.0 (12 0/00)	3.1 (2 0/00)	6.9 (4.6 0/00)						
IV	Greater than 3.6 (2.4 0/00)	Greater than 12.4 (8.3 0/00)	Greater than 6.4 (4.5 0/00)	Greater than 20.0 (13.3 0/00)								
V 2/	1.0 to 3.6 (0.7 to 2.4 0/00)	9.0 to 12.4 (6 to 8.3 0/00)	4.5 to 6.4 (3 to 4.5 0/00)	15.0 to 20.0 (12 to 13.3 0/00)			2.4 (1.6 0/00)	7.9 (5.3 0/00)	2.1 (1.4 0/00)	7.9 (5.3 0/00)		
VI 2/	0.1 to 3.6 (0.2 to 1.8 0/00)	7.0 to 12.4 (5 to 8.3 0/00)	1.5 to 6.4 (1.2 to 4.5 0/00)	11.0 to 20.0 (7.3 to 13.3 0/00)							0.3 (0.2 0/00)	3.1 (2.1 0/00)

1/ Bureau of Reclamation, 1972 0 mg/1 TDS converted to mmhos EC using the relationship: EC = TDS (1.5). Figures in parenthesis indicate approximate TDS in parts per thousand.

2/ Range of average salinities found within the group.

PLATE 3
SUISUN MARSH WATER SALINITY
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA

AUGUST 1974

0 — 1 — 2 MILES
SCALE 1:135,000

LEGEND

SUISUN MARSH STUDY AREA

- — — Study Area Boundary
- ▭ Ownership Boundories

PRESENT CONDITIONS NORMAL YEAR

- (1.0) Total Dissolved Solids p.p.t.
- 2.0 Electrical Conductivity (mmhos/cm)
- —— Wet Season
- — — Dry Season

LOCATION MAP


PLATE 4
SUISUN MARSH WATER SALINITY
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA
AUGUST 1974
SCALE 1:135,000
0
2 MILES
LEGEND
SUISUN MARSH STUDY AREA
Study Area Boundary
Ownership Boundaries
PRESENT CONDITIONS DRY YEAR
(1.0) Total Dissolved Solids p.p.t.
2.0 Electrical Conductivity (mmhos/cm)
Wet Season
Dry Season
SOLANO COUNTY
Suisun Marsh Study Area
LOCATION MAP
POTRERO HILLS
GRIZZLY ISLAND
HAMMOND
WHEELER ISLAND
SIMMONS ISLAND
RYER ISLAND
MORROW ISLAND
VAN SICKLE ISLAND
CHIPPS ISLAND
GRIZZLY BAY
HONKER BAY
SUISUN BAY
MONTEZUMA SLOUGH
NURSE SLOUGH
SUISUN SLOUGH
SACRAMENTO RIVER
Suisun City
Fairfield
Cordelia
Pierce Harbor
Mein's Landing
To Rio Vista
To Birds Landing
To Collinsville
To Benicia
SOLANO CO
CONTRA COSTA CO
SACRAMENTO CO
(10.0) 15.0
4.5 (3.0)
(11.0) 16.5
(3.5) 5.2
(4.0) 6.0
(12.0) 18.0
9.5 (13.0)
(4.3) 6.4
20.0 (13.3)
5.2 (3.5)
(2.5) 3.8
3.5 (9.0)
(8.0) 12.0
(7.4) 11.1
3.0 (2.0)
2.2 (1.5)

May 1973 through October 1973. A high reading of 10.5 mmhos E.C. (7.0 0/00) was obtained in September 1973.

Soils of this area are mostly Tamba mucky clay with a significant amount of Joice muck (Plate 1).

GROUP IV

This group is made up of duck clubs located in the southwest portion of the Marsh. The water needed to manage these clubs is obtained from tidewaters of Goodyear and Suisun Sloughs, and Grizzley and Suisun Bays.

Clubs within this group receive some freshwater via runoff from adjacent hills to the west.

Water salinities average greater than 12.4 mmhos E.C. (8.3 0/00) during the dry period and more than 3.6 mmhos E.C. (2.4 0/00) during the wet period of a normal year. In a dry year greater than 20.0 mmhos E.C. (13.3 0/00) and 6.4 mmhos E.C. (4.3 0/00) can be expected (Table 8, Plates 3 and 4).

The area south of Pierce Harbor is predominantly Reyes silty clay, the remainder of the group is a mixture of Reyes silty clay, Joice muck, and Tamba mucky clay (Plate 1).

GROUP V

Duck clubs in this group are centrally located in the Marsh (Plate 2). Tidal waters of Montezuma Slough, Grizzly Bay and their distributaries provide the means of water management for these clubs.

In a normal year, average water salinities range between 9.0 mmhos E.C. and 12.4 mmhos E.C. (6.0 and 8.3 0/00) during the dry period of a normal year and 1.0 mmhos E.C. and 3.6 mmhos E.C. (0.7 and 2.4 0/00) during the wet period. In a dry year, average water salinities range from 15.0 to 20.0 mmhos E.C. and 4.5 to 6.4 mmhos E.C. (10.0 to 13.3 0/00 and 3.0 to 4.3 0/00) - (Table 8, Plates 3 and 4).

Analysis of water samples taken during 1972-73 on Grizzly Bay indicated an average of 2.4 mmhos E.C. (1.6 0/00) during the wet months and 7.9 mmhos E.C. (5.3 0/00) during the months of May to October, the highest reading being 12.0 mmhos E.C. (8.0 0/00) in July. Water samples taken on the western portion of Montezuma Slough averaged 2.1 mmhos E.C. (1.4 0/00) during the months of November to March and 7.9 mmhos E.C. (5.3 0/00) from May to October, the high being 11.2 mmhos E.C. (7.5 0/00) in July.

The soils associated with the duck clubs in this area are Reyes silty clay, Joice muck and Tamba mucky clay (Plate 1).

GROUP VI

The duck clubs which make up this group are located in the southeast portion of the Marsh (Plate 2). This area is largely influenced by freshwaters of the Sacramento River, Montezuma Slough, Honker Bay and their distributaries, including Roaring River.

Water salinities in this area range from 7.0 to 12.4 mmhos E.C. (4.7 to 8.3 0/00) during summer and 0.1 to 3.6 mmhos E.C. (0.1 to 2.4 0/00) in winter during a normal year with an increasing salinity gradient from east to west. In a dry year, salinities range from 11.1 to 20.0 mmhos E.C. (7.4 to 13.3 0/00) during the dry period and 1.5 to 6.4 mmhos E.C. (1.0 to 4.3 0/00) during the wet period (Table 8, Plates 3 and 4).

Water salinities were monitored in Montezuma Slough at Montezuma Ranch Gun Club beginning in November 1972. During the wet period (November to March) an average of 0.3 mmhos E.C. (0.2 0/00) was recorded, while during the dry period (May to October) an average of 3.1 mmhos E.C. (2.1 0/00) was recorded. The highest reading 5.7 mmhos E.C. (3.8 0/00) for this area was recorded in July 1973.

Soils of most clubs in this group are Suisun peaty muck (Plate 1). The central portion of the Grizzly Island Wildlife Management Area and the area bordering Roaring River are composed of Valdez silty clay loam.

PRODUCTION OF SOME WATERFOWL FOOD PLANTS

Eight species of plants were sampled because of their importance as choice waterfowl food plants (George, et. al., 1965 and Mall, 1969) or because of their importance as major cover types (George, op. cit. and George, 1974). The results of the sampling are summarized in Table 9.

MARSH IMPROVEMENT

TABLE 9

AVERAGE PRODUCTION OF SEED AND EDIBLE GREENS FOR EIGHT PLANT SPECIES IN SUISUN MARSH (POUNDS PER ACRE).

Plant	Seed	"Greens" 1/	Total
Alkali bulrush	1,320	--	1,320
Baltic rush	0	--	--
Brass buttons	50	1,670	1,720
Fat hen	2,100	--	2,100
Olney bulrush	8	--	8
Pickleweed	475	1,902	2,377
Saltgrass	6	--	6
Tule	37	--	37

1/ Dry weight.

The average production of seed for alkali bulrush from samples taken on five clubs was 1,320 lbs./ac. In addition to seed, green leafage on young plants and tubers are eaten by waterfowl; however, these were not sampled. Seed production of alkali bulrush ranged from 58 to 3,770 lbs./ac. on the clubs sampled (Table 10). The least production occurred on the two clubs which had drained their ponds at the end of the waterfowl hunting season. The highest average seed production and the greatest vegetative growth occurred on the club which had a continuously flooded condition throughout the year. However, this extended period of flooding was caused by a broken levee and did not result from normal management practices. Periods of extended flooding eventually produce dense, undesirable stands of vegetation.

TABLE 10

SEED PRODUCTION OF ALKALI BULRUSH UNDER VARIOUS TYPES OF WATER MANAGEMENT

Club Name	Water Management	Average Plant Height (Ft.)	Seed Produced (lbs./ac.) Range	Mean
Teal D.C.	Continued flooding	4.0	2,065-2,992	2,513
Spoonbill D.C.	Extended flooding	3.5	1,237-3,770	2,394
Gum Tree Farm	Spring irrigation	3.5	1,037-1,566	1,297
Garibaldi D.C.	Drain end of season	2.5	160-398	269
McCrory D.C.	Drain end of season	2.0	58-244	130

The club located on Van Sickle Island, Spoonbill Duck Club, was flooded for a longer period than is recommended in Type I water management (Figure 9 - Section on Management Practices) and also had a high amount of seed production, the greatest amount occurring where some surface water was still apparent in August when samples were obtained. The samples obtained on Gum Tree Farm were about average for seed produced and the vegetation was less dense than in the more extensively flooded clubs. This club follows the District recommended water management schedule.

The Baltic rush samples were obtained in dense, established stands. No mature seeds were obtained (Table 9).

Brass buttons, which was sampled in May 1973, was measured for both seed and "greens" produced. In pure stands of brass buttons approximately 50 lbs./ac. of seed was produced. The greens in these samples amounted to about 13,595 lbs./ac. as green forage and 1,670 lbs./ac. when dried. The total food available from seed and greens amounted to 1,720 lbs./ac. (Table 9).

Fat hen was sampled on two clubs. One club located near Bahia had fat hen which had recently been flooded in preparation for waterfowl season and another stand which had not yet been flooded. The newly flooded fat hen had turned reddish and the seed had reached maturity. The stand not yet flooded, remained purple and the seeds were not mature. This phenomenon was noted in other locations also. Fat hen produces dimorphic seeds, one being black and approximately 1/3 the size of the larger, dark brown or rusty colored seed. The small mature seed amounted to four times the weight of the large seed in one sample (4 to 1 ratio) and 15 times as much in the other sample - a 15 to 1 ratio. The average amount of seed produced was 2,100 lbs./ac. (Table 11).

The Olney bulrush samples produced approximately eight pounds of seed per acre.

TABLE 11

FAT HEN SEED PRODUCTION (POUNDS PER ACRE)

Club			Small Seed	Large Seed	Total
Mulberry Land Co.	1.	Mature	594	142	736
	2.	Immature	---	---	425
Teal Duck Club			3,396	226	3,612
				Average	2,100

The seeds of pickleweed are imbedded in the terminal segments of the plant which are removed intact by feeding waterfowl. Because of the difficulty of removing the seed from this terminal segment the weight of the seed was approximated as 20 percent of the total weight of the dried terminal segment. The average seed production for pickleweed was estimated to be 475 lbs./ac. The total weight of seed and terminal segment amounted to 2,377 lbs./ac. (Table 9).

Saltgrass was sampled within an established stand. Only 50 percent of the spikelets were pistillate and approximately six pounds of seed were produced per acre (Table 9).

Tule sampled indicated seed production of about 37 lbs./ac. (Table 9).

Cattails were not sampled. Their small airborn seeds contribute little or nothing to the diet of waterfowl. The starchy base of small plants and some rhizomes are eaten by geese but mature stands seldom are used by waterfowl as food.

Alkali bulrush, fat hen and brass buttons appear to have the best potential of those sampled to provide significant quantities of food per acre for waterfowl use.

RESULTS OF SOIL AND WATER QUALITY STUDIES

Soil and water salinity (electrical conductivity) and pH were monitored at five duck clubs in the Suisun Marsh from November 1972 through January 1974. The soil and water quality monitoring program was conducted to determine the relationship of these paramenters with location in the Marsh and type of water management. Water samples obtained on the clubs were taken from circulation ditches for the most part. Therefore, water samples could subsequently be obtained during periods when ponds were drained or nearly drained. Soil samples were only obtained in stands of alkali bulrush. The growth of alkali bulrush in the areas sampled was generally representative of stands of this plant on the club. Since the samples were obtained only where alkali bulrush was growing, the data does not necessarily represent the condition prevalent on all parts of the club. However, the data provides some information on the range of conditions under which alkali bulrush was growing and serves as a base from which the various clubs could be compared.

The five clubs at which monitoring was conducted (Plate 5) and some prominent conditions found are as follows:

A. Montezuma Ranch - located at the southeast end of Montezuma Slough on Van Sickle Island (the area of the Marsh generally receiving the least saline water), no spring flood-drain cycles were utilized during 1973;

B. B & O Sportsman - located in the northeast corner of the Marsh at Denverton Slough, spring flood-drain cycles not used;

C. Paton Place - located on Grizzly Island adjacent to Gum Tree Farm, normally spring flood-drain cycles not used, this club couldn't circulate 1/ water in the pond monitored because of physical restrictions;

D. Gum Tree Farm - located on Grizzly Island, follows the District's recommended water management schedule, circulates water, etc, and;

E. Mulberry Co. - located in the southwest corner of the Marsh (the area receiving the most saline water), uses one flood-drain cycle after waterfowl season, and circulates water.

At Montezuma Ranch the water available was significantly less saline than that in the other locations monitored in the Marsh (Figure 3). In the past this club has generally followed a spring flooding program, but during the season monitored spring irrigation was curtailed to facilitate burning of undesired vegetation. Ponds were drained by the end of March 1973. In spite of the availability of relatively fresh water it is readily apparent that even in this area of the Marsh, if deprived of spring flooding, a rapid rise in soil salt concentration can be expected (Figure 4). The stand of alkali bulrush in which soil samples were obtained grew under great stress. The mature plants averaged less than

---

1/ Circulation in this report means water enters the club from an outside source, such as a Slough or Bay, passes through the club, and exits off the club through an outlet pipe.

PLATE 5

SOIL AND WATER SAMPLING SITES
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA

AUGUST 1974

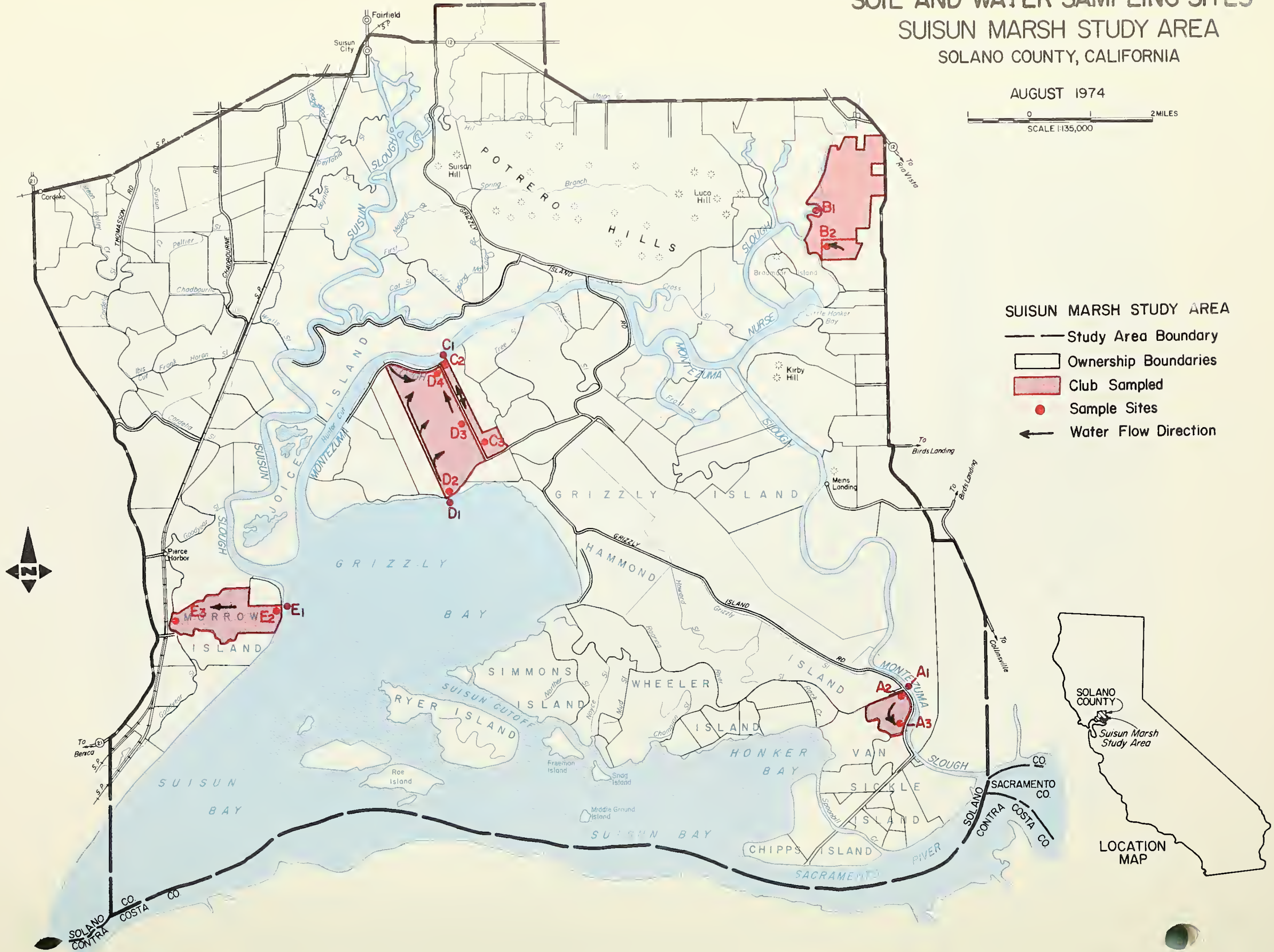
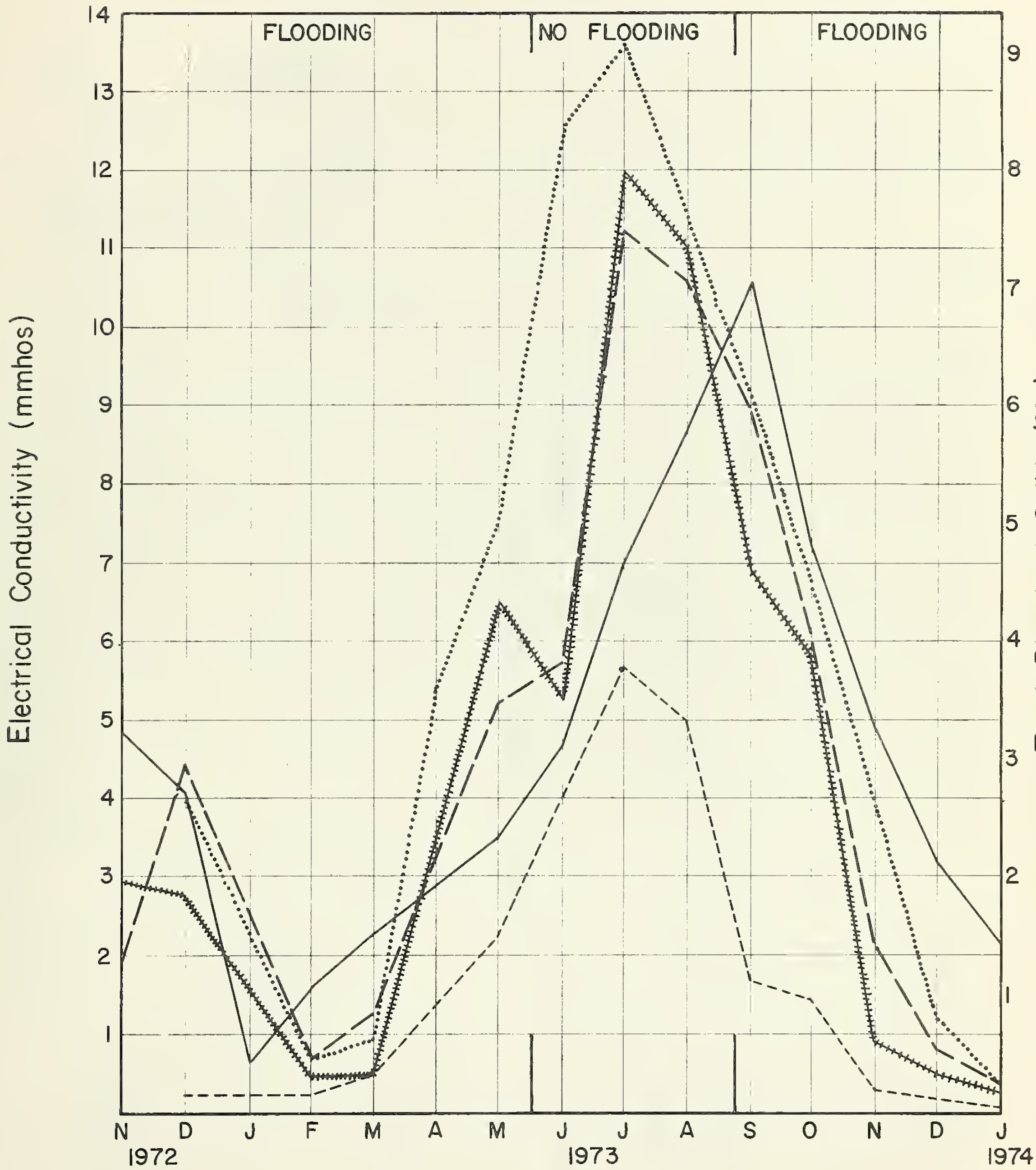


Figure 3

ELECTRICAL CONDUCTIVITY FOR MAJOR WATER SOURCE MONITORED FROM 11/72 TROUGH 1/74



----- Montezuma Ranch - Montezuma slough

——— B & O Sportsman - Denverton slough

— — Paton Place - Montezuma slough

+++++++ Gum Tree Farm - Grizzly Bay

.... Mulberry Land - Suisun Bay (Apr. through Aug. - Bureau of Recl. data - Site D-7)

Figure 4

SOIL AND WATER QUALITY AT MONTEZUMA RANCH

LEGEND

? Incomplete data for month

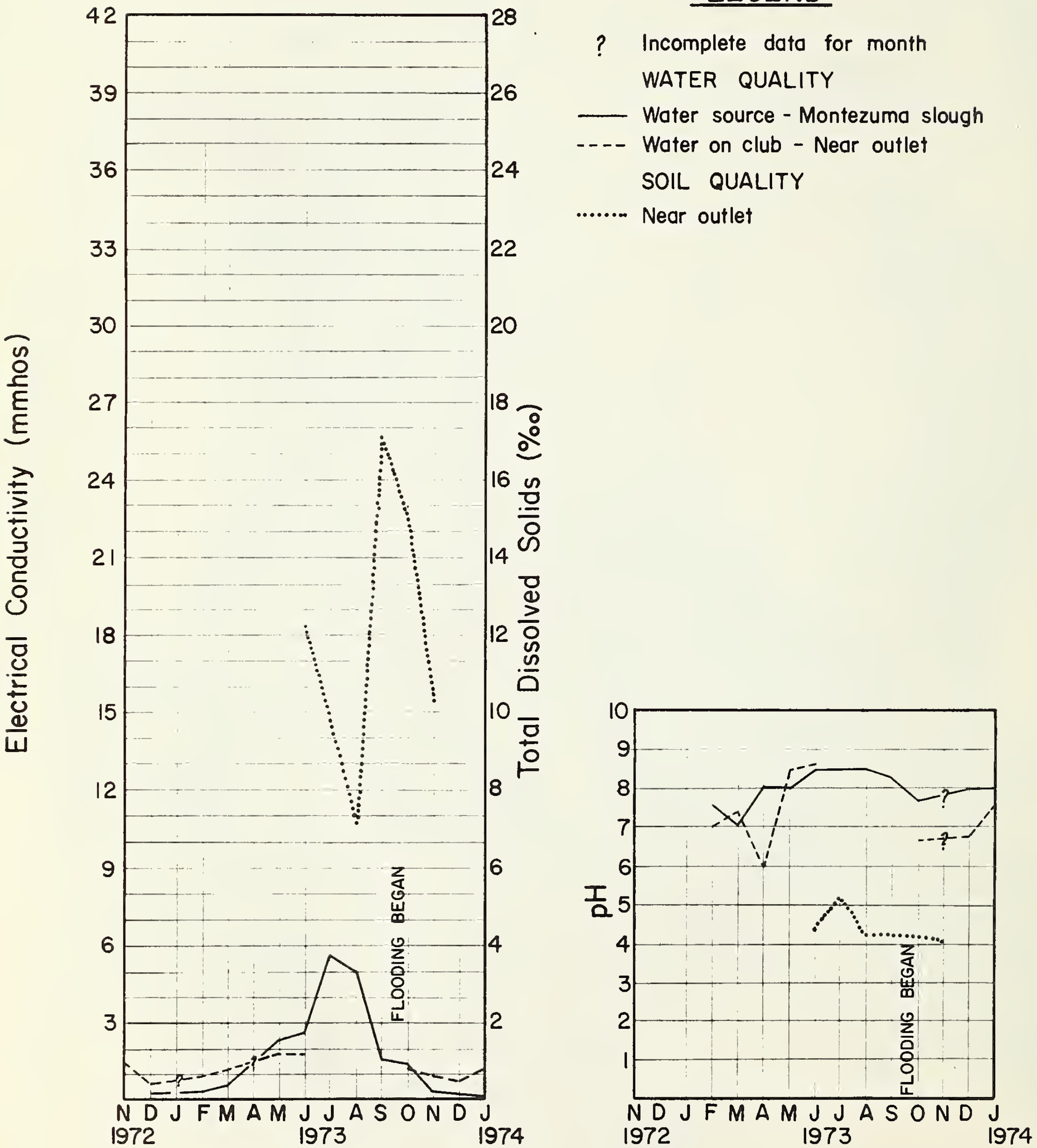
WATER QUALITY

——— Water source - Montezuma slough

- - - - Water on club - Near outlet

SOIL QUALITY

······· Near outlet



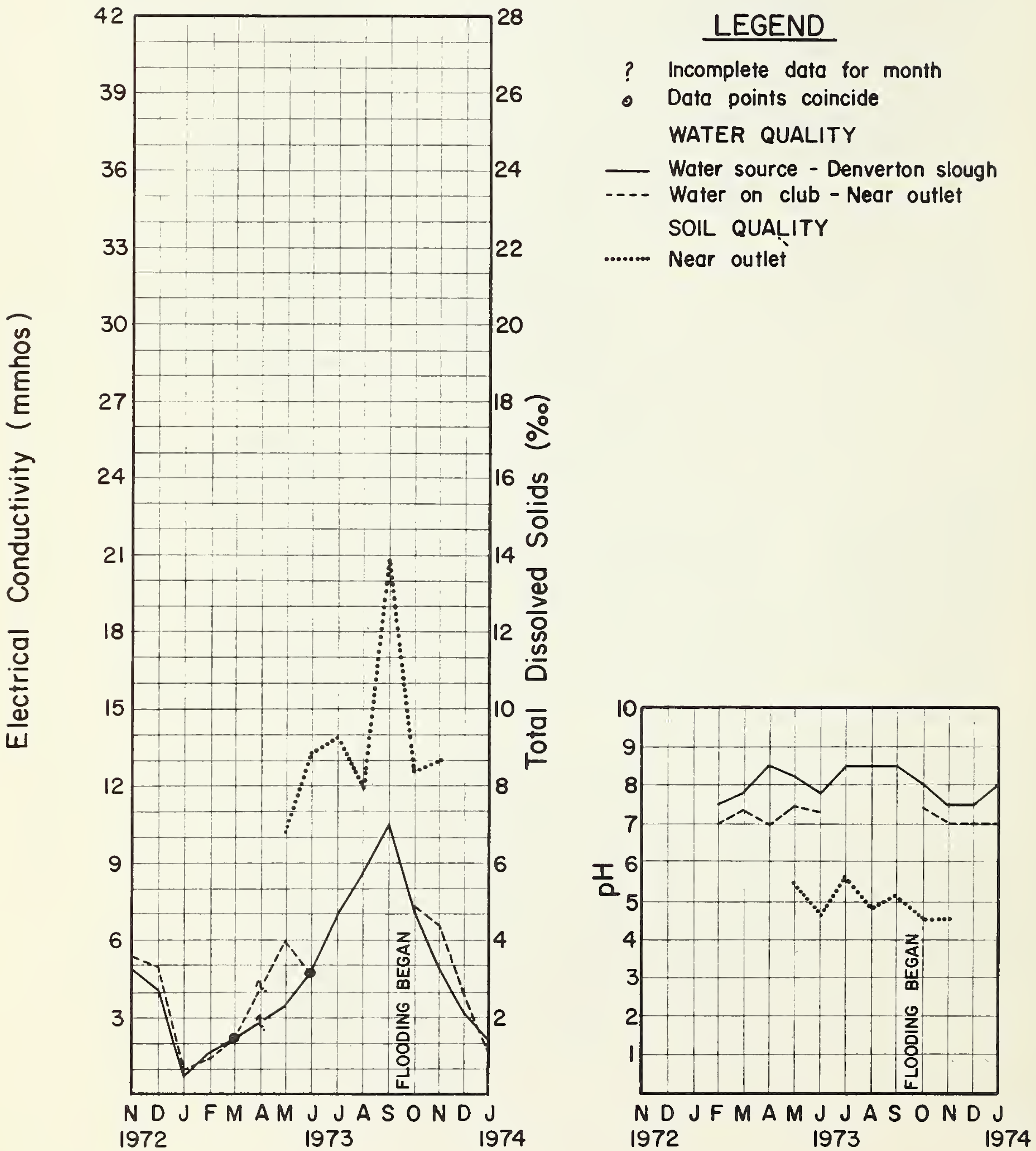
one foot in height, approximately 10 percent developed seed heads and seed production was minimal. Soil salinities were within the range suitable for growth of alkali bulrush, but, the lack of adequate soil moisture during May and June inhibited growth. The soil was highly acidic, reaching a pH of 4.2.

At the B & O Sportsman Club the source of water, Denverton Slough, was somewhat more saline than water available at the southeast portion of the Marsh at Montezuma Ranch (Figure 3). But during the critical period needed for seed production (April, May and June), it was well within required levels. During late spring the water was less saline than that available at the other sites, exclusive of Montezuma Ranch. Unlike the other sites sampled where peak salinities were recorded in July, salinity levels here did not peak until September, two months later. This area is further removed from the sources of water, i.e. the river at Collinsville and Grizzly Bay. Apparently there was a lag period in tidal dilution that caused this delay in the peak. The result was that at the onset of flooding in preparation for the 1973-74 waterfowl season, salinity levels were at their highest in Denverton Slough, whereas, salinity levels had been dropping by this time at the other sites. Soil salinity reached a peak of nearly 21.0 mmhos E.C. (14 0/00) in September (Figure 5). Water quality in the ponds followed that of Denverton Slough, except in April and May. Soil pH ranged between 4.6 and 5.6.

Historically, early (January and February) drainage has been practiced on the club. This year the ponds were also drained by March but the lack of spring flooding inhibited the growth of alkali bulrush. Alkali bulrush made up only 2 percent of the vegetative cover. Pickleweed and saltgrass were the predominant cover types making up 32 and 26 percent of the cover respectively. Bare ground made up 8 percent of the area. Although soil samples were not obtained in locations other than where alkali bulrush was dominant, and since more salt tolerant plants and bare ground prevailed, it may reasonably be assumed that much higher soil salinities dominate on the club.

Soil and water quality was monitored on Gum Tree Farm and Paton Place primarily to evaluate water circulation or the lack of it. Paton Place obtains water from Montezuma Slough. The portion of the club monitored lacked water circulation facilities in that the two water control structures used were located at the same end of the club, adjacent to each other. Both were used for flooding and draining and were connected to the same main ditch. Consequently, water moved back and forth on the club at one end, precluding the efficient circulation of water (see Plate 5, Sample Sites C-2 and 3). At initiation of flooding, prior to the waterfowl season, some of the salt which had accumulated at the surface of the soil during the summer was picked up by the incoming

Figure 5
SOIL AND WATER QUALITY AT
B & O SPORTSMAN



water and carried to the upper end. The lack of an outlet prevented its elimination and the salt content in the soil increased at the far end of the club. Figure 6 gives the data collected on Paton Place. Typically, spring irrigation has not been used on Paton Place, however, during the season monitored, a broken water control structure prevented complete removal of water. If the usual water management had been carried on during the season of observation, an even greater increase in soil salinity might have been expected.

Gum Tree Farm obtains water primarily from Grizzly Bay but supplements from Montezuma Slough. The water quality of sources for both Gum Tree and Paton Place (Grizzly Bay and Montezuma Slough) was similar (Figure 3). Gum Tree's system circulated water through the club. At the onset of flooding on Gum Tree Farm, salts at the surface of the soil were flushed out of the club and rapid reduction in soil salinity occurred (Figure 7). In June, as drying of soils commenced, the soil acidity increased and the pH dropped to 4.4 in July.

It is readily apparent from these data that the presence of a system allowing water circulation is essential for efficient salinity control. The abundance of alkali bulrush and fat hen produced on the Gum Tree Farm Club also substantiates this.

On Mulberry Land Company, water is obtained primarily from Suisun Bay. Water is obtained additionally from Goodyear Slough when initially flooded, thereafter water is circulated through the club with outlets into Goodyear Slough. Water salinities were somewhat higher in Suisun Bay than in the other areas monitored and considerably higher than that near Van Sickle Island at the Montezuma Ranch (Figure 3). A gradation of soil salinity was apparent with the higher salinity located at the outlet end of the club (Figure 8). Consequently, alkali bulrush, brass buttons and fat hen predominated near the inlet, and pickleweed predominated through the middle of the club and at the outlet end. Bare, salt encrusted soil also occurred near the outlet end of the club during the summer.

Alkali bulrush and fat hen comprised 20 and 18 percent of the cover respectively, and pickleweed made up nearly 37 percent. Soil acidity reached a pH of 4.7 shortly after the ponds were drained here also.

Although a more extensive soil and water quality study would be desired to establish a statistically valid relationship between water management and the resulting soil salinity and plant response, these data serve as indicators. It is apparent that under present water quality conditions a combination of water circulation and spring flooding are essential prerequisites to desirable waterfowl habitat development in Suisun Marsh, particularly where alkali bulrush, fat hen and brass buttons are the desired waterfowl food plants.

Figure 6
SOIL AND WATER QUALITY AT PATON PLACE

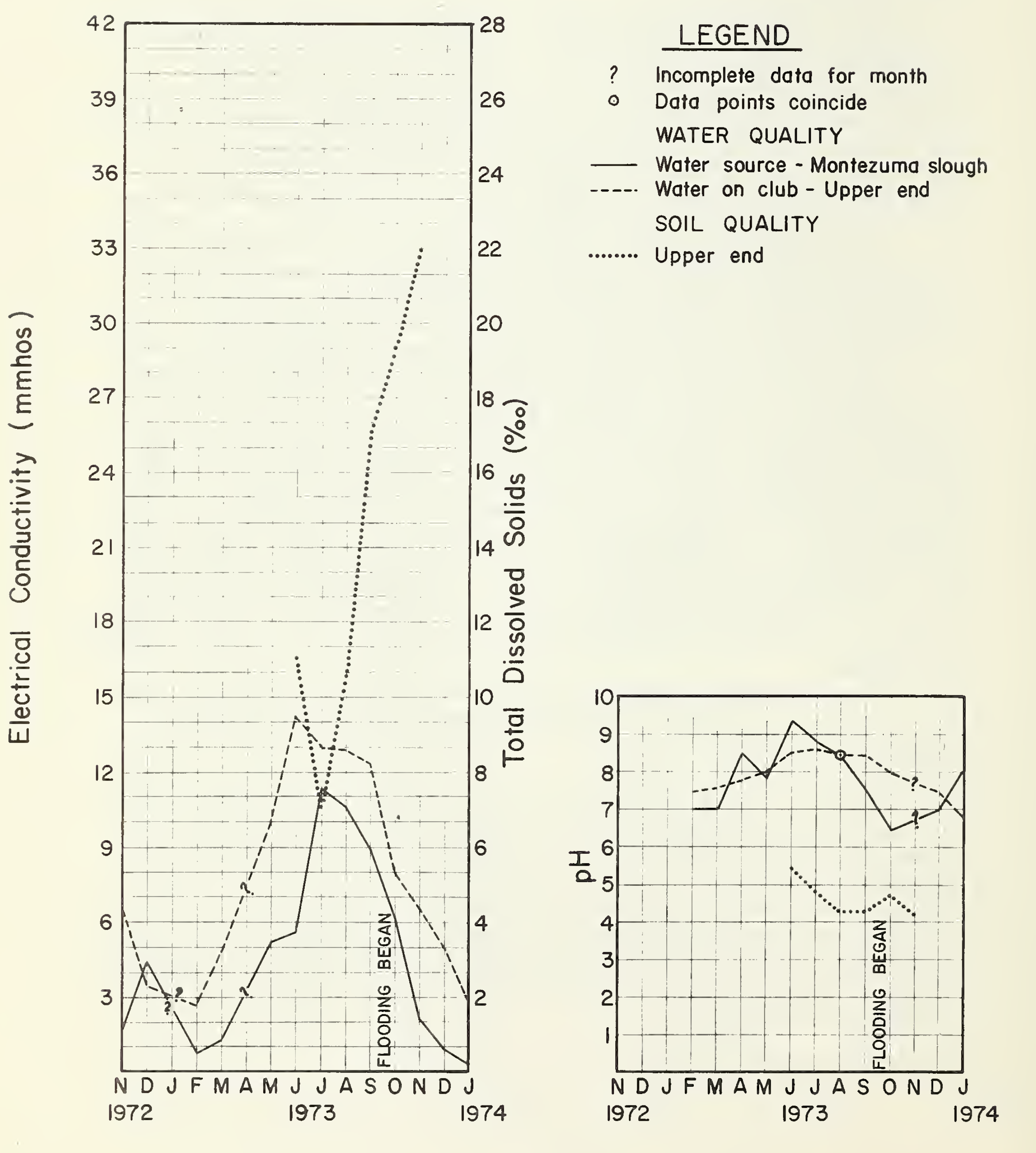


Figure 7
SOIL AND WATER QUALITY AT
GUM TREE FARM

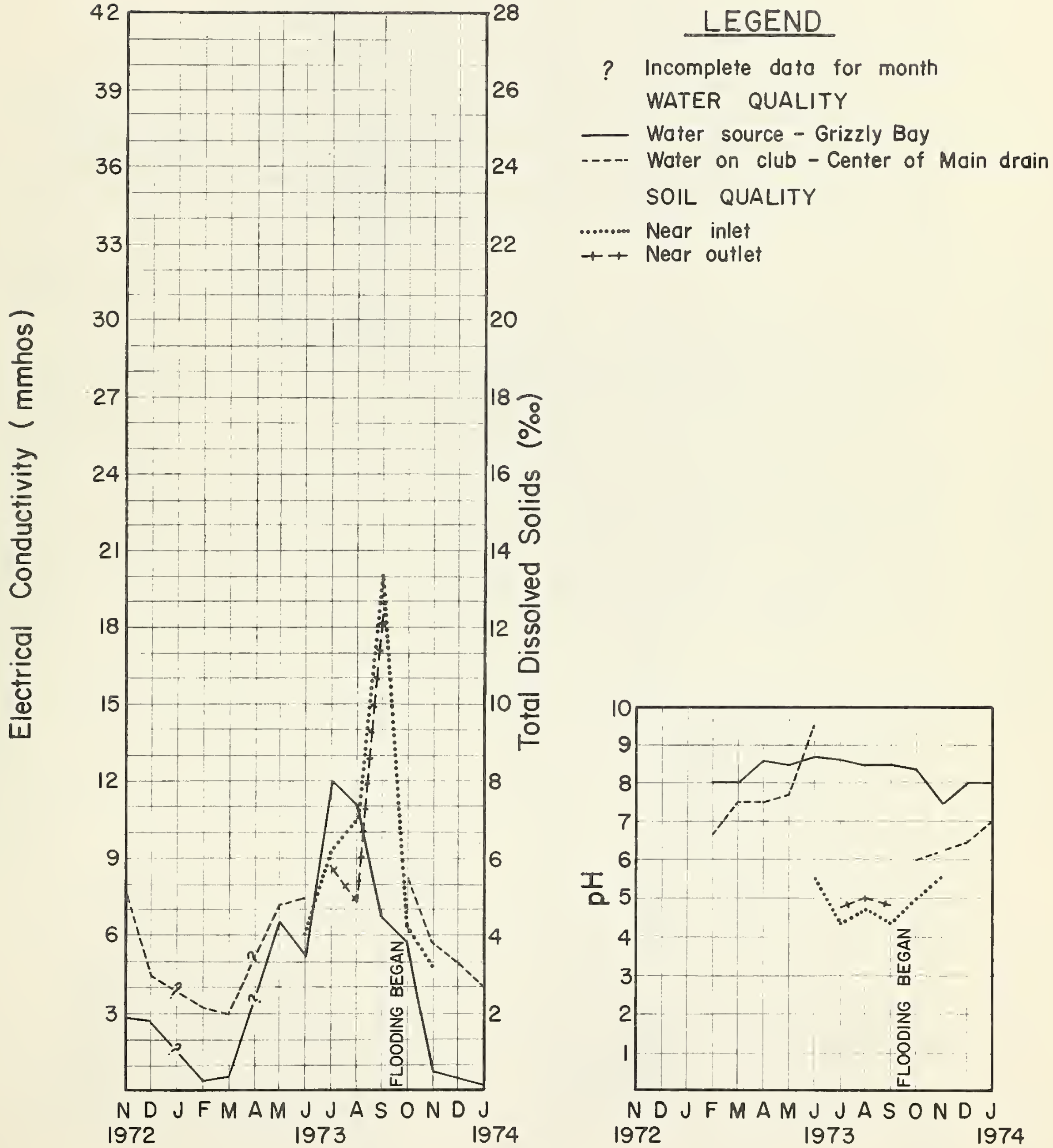
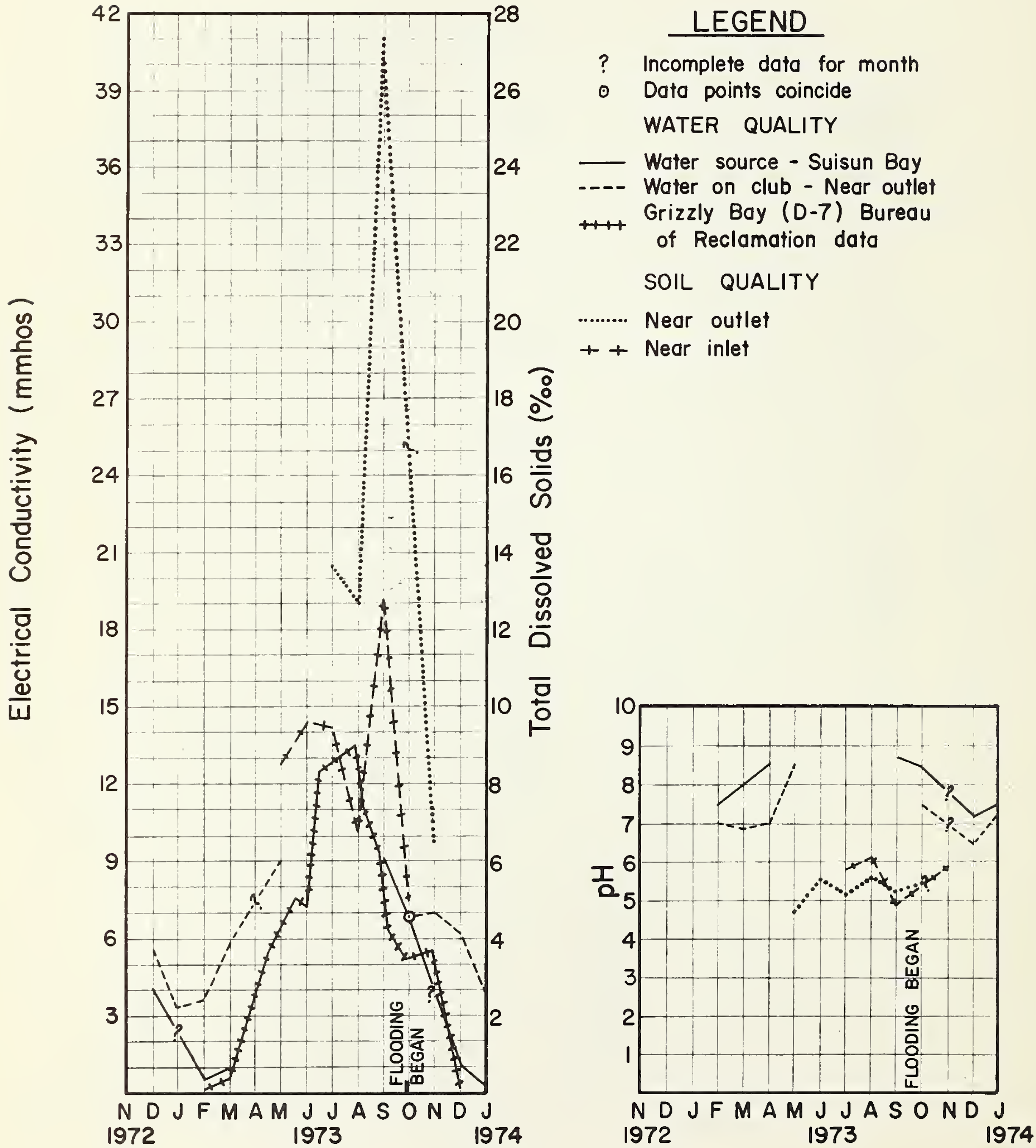


Figure 8
SOIL AND WATER QUALITY AT
MULBERRY LAND CO.



Soil pH ranged between 4.2 and 6.1 during the summer with the most highly acid condition, pH 4.2, occurring in the area with the freshest water conditions (Montezuma Ranch - Figure 4). The lowest pH readings occurred when the ponds were dry. The effect of the strongly acid soil on plants was probably masked by the effect of high osmotic pressure - the result of reduced soil moisture and increased soil salinity during the summer.

INVENTORY OF PRIVATE DUCK CLUBS

Approximately 45,710 acres of marshland in Suisun Marsh are privately owned. The lack of up-to-date knowledge on physical facilities, management, and habitat prompted a field inventory of duck clubs to obtain information as to the present condition of private clubs in the Marsh. From this, projections could be made to show future needs for water and physical improvements to provide better habitat management.

PHYSICAL INVENTORY

During the inventory period there were 144 individual units being managed by privately owned duck clubs in Suisun Marsh (Plate 6, Pocket in side Cover.. Actually there were 151 clubs but some shared the same water control facilities.) One hundred nine of these clubs (units), 76 percent, were inventoried (Plate 7). The total acreage inventoried was 30,006 acres, or 67 percent of the privately owned marshland. The average size of the 109 duck clubs was 256 acres ranging in size from 50 to 1,138 acres. Of the clubs inventoried, 21,054 acres (70%) were seasonally flooded and 619 acres (2%) were managed as permanently flooded ponds (Table 12). Tidelands accounted for 1,082 acres (4%) and areas considered to be upland amounted to 7,251 acres (24%).

Other physical features inventoried include (1) length, width and depth as well as condition of main ditches, spreader ditches and sloughs located within clubs, (2) length, height, top width, and condition of main (outside) levees and interior levees, and (3) basic data on water control structures, including conduits used to pass water through levees. Condition ratings of excellent, good, fair and poor were assigned to levees and ditches (Table 13 and Photos 2 and 3) on the basis of criteria listed in Appendix IB. Management of the Marsh depends on these basic facilities and it is imperative that they be in good condition in order to follow a marsh management plan.

In total, 109 clubs were surveyed; however, complete information on physical facilities was available from only 93 clubs. Lengths of time required to flood and drain given areas were available from 81 clubs. While data from State of California

PROPERTY OWNERS IN SUISUN MARSH - Index to PLATE 6

GROUP I		GROUP II		GROUP III	
No.	Property Name	No.	Property Name	No.	Property Name
1	Antioch Duck Club	32	Anglo Calif. Natl. Bank, Trustee	49	B & O Sportsman Club
2	Arnold Ranch, Inc.	33	Black Mallard Duck Club	50	Blacklock, J.
3	Chadbourne, F. Jr. 1/	34	Brazelton, J.	51	Broadmoar West
4	Cordelia Duck Club	35	Gray Goose Duck Club	52	Can Can Club
5	Cygnus Club	36	Hopkins, J. S.	53	Davisson, W.
6	Family Gun Club	37	Jacksnipe Gun Club	54	Denverton Lowland Club
7	Franciscan Gun Club	38	Joice Island Mallard Farm	55	Engel Duck Club
8	Garibaldi Bros. Duck Club	39	Larquier, A.	56	Greenhead, Inc.
9	Golden Gate Duck Club	40	Marshlands Duck Club	57	Gunn Ranch Duck Club
10	Green Lodge Land Company	41	North Frost I	58	Lambie, M.
11	Horseshoe Duck Club	42	North Forst II	59	Lyton Pond
12	Ibis Duck Club	43	Old Valante	60	Machado Gun Club
13	Mallards Inn Duck Club	44	Pollard, C.	61	Poopdeck Duck Club
14	Mira Monte Club	45	Shelldrake Duck Club	62	Potrero Duck Club
15	Mrs. Murphy's Duck Club	46	Suisun Farm	63	Soares, J.
16	Nelson Buick, Inc.	47	Tule Farm	64	Stolte Duck Club
17	North End Duck Club	48	Walnut Creek Gun Club	65	Tule Meadow Duck Club
18	Ornbaun, G.			66	Wagenet Duck Club
19	Pagli, W.			67	Walter, R.
20	RBM Land Company			68	Westwind Duck Club
21	Rousseau Ranch			69	Westwind I
22	Side by Side Club				
23	Simmons and Mayer Duck Club				
24	Sprig and Teal Club				
25	Suisun Marsh Hunting Pres. 2/				
26	Sunrise Duck Club				
27	Sweetwater Duck Club				
28	Teal Duck Club				
29	Teal No. 3 3/				
30	Tule Belle Duck Club				
31	Whistler Duck Club				

1/ Primarily upland - livestock grazing.
2/ Primarily upland - pheasant hunting.
3/ Portion of old Teal Duck Club with no name.

PROPERTY OWNERS IN SUISUN MARSH - Index to PLATE 6 (Continued)

GROUP IV		GROUP V		GROUP VI	
No.	Property Name	No.	Property Name	No.	Property Name
70	Bowman Property	82	Annie Mason Point	121	Annie Oakly Rod & Gun
71	Goodyear Club	83	Balboa Gun Club	122	Arroyo Grande
72	Goodyear Land Dev. Co.	84	Benson, E. (Grizzly King)	123	Blue Wing Teal Club
73	Mayne Duck Club	85	Bent Barrel	124	Canvasback Farms
74	Morrow Island Land Co.	86	Black Dog Gun Club	125	Cavanaugh, L.
75	Mulberry Land Co.	87	California Land Co.	126	Cesa Farms
76	Pahl, J.	88	Crescent Gun Club	127	Concord Farms
77	Pintail Lodge	89	Delta King	128	Dante
78	South Bahia Club	90	Fairview Gun Club	129	Delta Farms
79	Sprig Haven	91	Frost Ranch	130	Gray Island
80	Stone, E.	92	Grizzly Duck Club	131	Grizzly Island Wild. Area 4/
81	West Family Club	93	Grizzly Island Ranch Hunt. Pres.	132	Hit and Miss
		94	Grizzly Land Company	133	Honker Bay Association
		95	Gum Tree Farm	134	Honker Farms Duck Club
		96	Hendricks etal Duck Club	135	Island Farms
		97	Honker Club	136	Island Gun Club
		98	Island Club	137	Mallard Ranch
		99	Joice Island Gun Club	138	Meins Landing Farms, Inc.
		100	Joice Island Wildlife Area 4/	139	Montezuma Ranch
		101	Kellog, L. 5/	140	Nimrod Farms
		102	Long Point West Land Company	141	Nine Land Company
		103	Markstein Farms	142	North Roaring River
		104	Mendoza Gun Club	143	Reyman Duck Club
		105	Meridian Gun Club	144	Riverside Club
		106	Montezuma Gun Club	145	Roaring River Ranch
		107	Olson & Perez	146	San Souci Land Company
		108	Paton Place	147	Spoonbill Duck Club
		109	Pintail Ranch	148	U. S. Navy
		110	Rich Island Gun Club	149	Van Sickle Gun Club
		111	Schafer	150	Webfoot Gun Club
		112	Simmons Island Land Company	151	Wheeler Island Gun Club
		113	Sprig Farms		
		114	Sprigsville Ranch		
		115	Tipend Gun Club		
		116	Tree Slough		
		117	Weston, H. 6/		
		118	Westwind II		
		119	Windmill Gun Club		
		120	Whistling Wings		

4/ State of California
5/ Primarily cropland and pasture
6/ Primarily pasture

PLATE 7

SUISUN MARSH INVENTORY
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA

JULY 1974

SCALE 1:135,000 (0 – 1 – 2 MILES)

SUISUN MARSH STUDY AREA
- Study Area Boundary
- Ownership Boundaries

SUISUN MARSH INVENTORY
- Inventoried duck clubs
- Clubs not inventoried but some information available
- Clubs not inventoried
- Private land not inventoried
- Federal and State lands

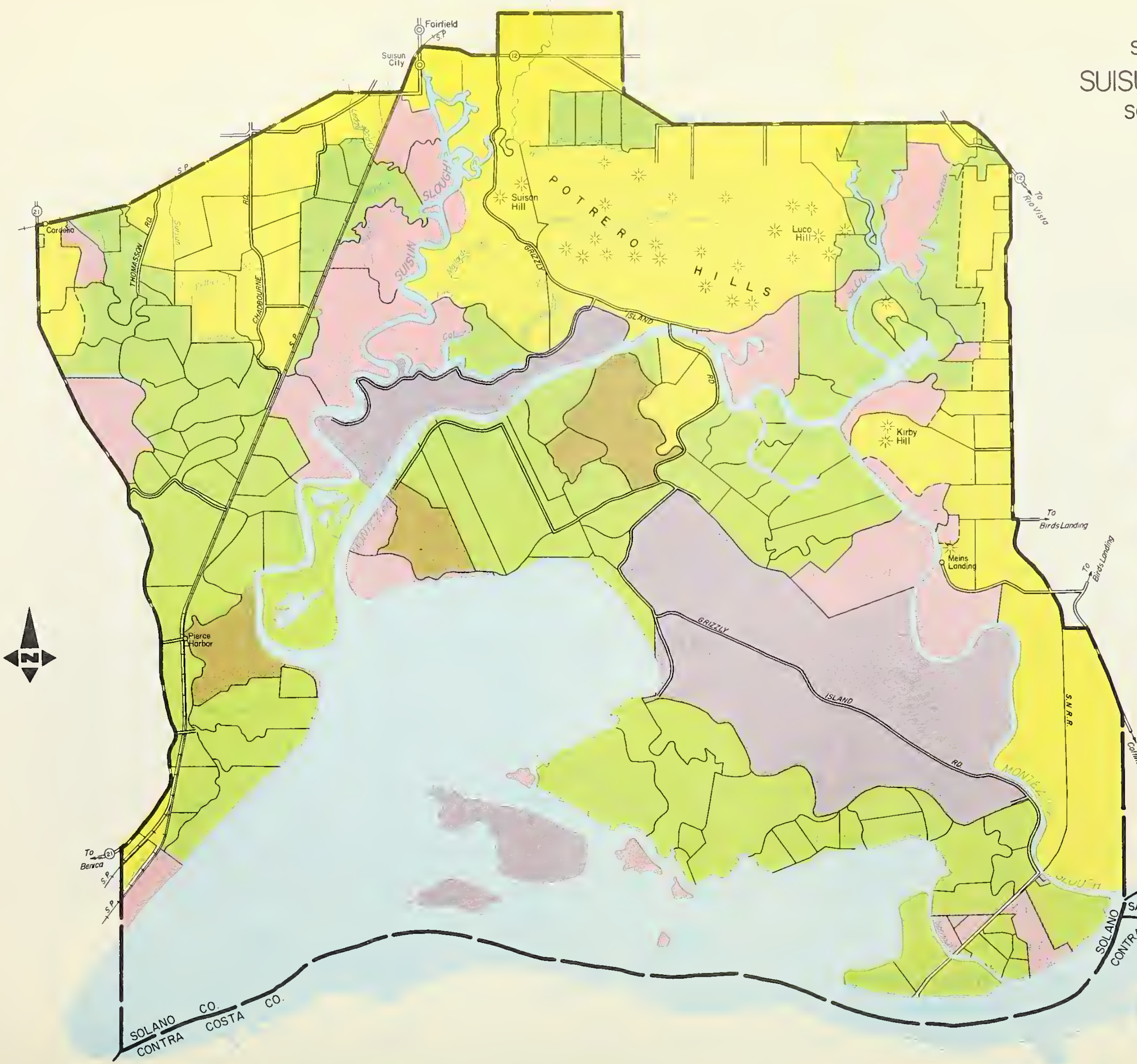


TABLE 12

SUMMARY OF LAND AREAS FOR 109 PRIVATE DUCK CLUBS INVENTORIED IN SUISUN MARSH, 1973

Group	Number of Clubs	Total Acreage	Land Types (acres) Seasonally Flooded	Permanent Ponds	Tide-land	Upland
I	26	6,156	4,697	50	0	1,409
II	11	2,298	1,273	173	60	792
III	12	3,183	1,763	296	274	850
IV	8	2,099	1,758	0	0	341
V	29	10,846	7,329	0	545	2,972
VI	23	5,424	4,234	100	203	887
Total	109	30,006	21,054	619	1,082	7,251

TABLE 13

SUMMARY OF CONDITION OF DITCHES AND LEVEES ON THE SUISUN MARSH DUCK CLUBS INVENTORIED.

Physical Feature	Percent of Clubs Having Condition Type 1/ Excellent	Good	Fair	Poor
Levees Exterior	5	51	33	11
Levees Interior	2	56	30	12
Ditches Main	9	71	18	2
Ditches Circulation	2	53	40	5

1/ See Appendix 1B for definition of conditions.

Photo 2. The "Marsh Monster" used to clean out spreader ditches.

Photo 3. A spreader ditch after being cleaned out by the "Marsh Monster".

properties were used to determine total water needs, it was felt that the physical information provided by private clubs represented an adequate sample with data which could be extrapolated to encompass the entire Marsh.

Levees

Levees are an integral part of marsh management (Photos 4 and 5). The larger exterior levees prevent uncontrolled flooding and must withstand wave forces and tidal action. Interior levees enable property owners to apply some degree of individual water management within the leveed portions of their property.

Information on exterior levees was provided by 96 clubs. On these 96 clubs, there were 129.74 miles of exterior levees, or an average of 1.35 miles per club. The average height of these levees was 6 feet and the average top width was 18 feet with an outside slope of 2:1 and an inside slope of 1 1/2 to one. These dimensions represent 6.33 cubic yards of fill per lineal foot of exterior levee and an average volume of fill in main levees of 45,120 cubic yards per club. By expanding this information, the total length of exterior levees on the 144 clubs in the Marsh was estimated to be 194.40 miles and from this the total volume of fill in these levees was calculated to be 6,497,314 cubic yards.

The inventory revealed that 51 clubs had main levees smaller than the average computed for the Marsh. An estimation was made of the amount of fill required to bring all exterior levees up to an average height of 7 feet and an average top width of 22 feet with side slopes at 2 to 1 and 1 1/2 to 1. The intent of this enlargement is <u>not</u> to make all levees within the Marsh the same height and width, but to arrive at average dimensions that compensate for raising all main levees 1 foot, depending upon their location, and bringing inadequate levees up to the average for the area in which they are located.

Deficient levees existed on 51 of the 96 clubs inventoried. Bringing these levees up to standard would require the addition of approximately 2.55 cubic yards of fill per lineal foot of levee. With an average levee length of 7,128 feet per club, the amount of material needed to improve 51 substandard levees to standard would be 926,996 cubic yards. Projections based on the above relationship (using the number of clubs with substandard levees, the number inventoried, and the total number of clubs in the Marsh) indicate 1,385,042 cubic yards of fill would be needed to bring all inadequate levees up to standard.

The second type of levee is a lower, interior levee used to control and spread water or separate ponds. There were 93 clubs that provided information on interior levees. The average height, top width and side slopes were 3.5 feet, 18 feet, 2 to 1 and

Photo 4. Dragline used for constructing and repairing levees and ditches.

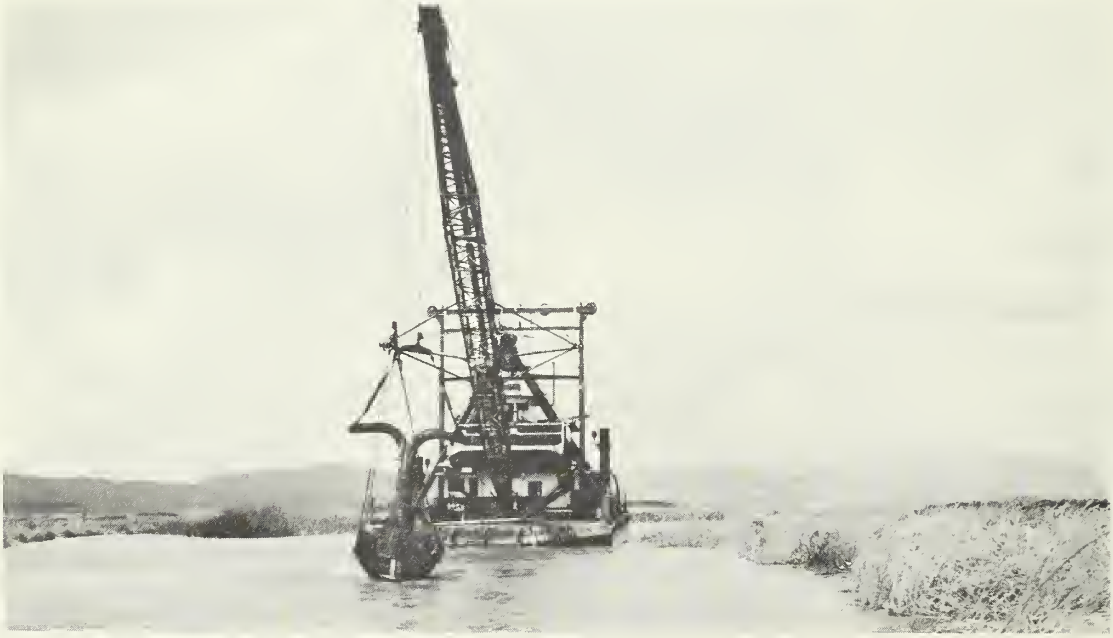


Photo 5. Floating dredge used for constructing and repairing exterior levees and cleaning tidal inlets and outlets at water control structures.

1 1/2 to 1 respectively. The volume of earth in these levees averaged 3.13 cubic yards per lineal foot. The 93 clubs reported 704,695 lineal feet of interior levees which represents an average of 7,577 feet of levee per club. Again assuming that the 93 clubs sampled were representative of the entire 144 clubs present in the Marsh, an estimated 3,415,268 cubic yards are contained in these interior levees.

The average interior levee was considered adequate. Fifty of the 93 clubs surveyed had subaverage levees. These levees had a height of 2.6 feet and a top width of 12 feet. Side slopes were the same as the average interior levee. The volume of these subaverage levees was 1.6 cubic yards per lineal foot. Therefore, it would be necessary to add 1.5 cubic yards of fill per lineal foot of levee in order to raise inadequate levees to the average. By expanding this information to include all substandard interior levees present on private clubs, it was estimated that an additional 903,381 cubic yards of earth would be required to bring all levees up to standard.

Flooding

The data collected from 97 of the 109 clubs surveyed indicated size, number, purpose and location of water control structures on each club. Also included in the inventories, were the size of ponded areas and the average pond depth. Lengths of time required to flood ponds were obtained from 81 of the 109 clubs inventoried.

Water control structures varied from 12 to 54 inches in diameter, consisting usually of corrugated metal pipe as well as some wooden structures (Photos 6, 7 and 8). A few pumps have been installed (Photo 9). The average cross-sectional area was determined for all clubs inventoried and the average area was related to acreage flooded. The average opening per 100 acres flooded was 7.407 square feet which is about equal to the cross-sectional area of a pipe with a 36 inch diameter. The average pond depth was 1.25 feet, based on measurements from four randomly selected clubs with ponds flooded to shooting level.

Determining if an average of one 36 inch pipe per 100 acres flooded was adequate to flood during a reasonable period of time required consideration of the following factors: (1) the average difference between shooting level and the average elevation of the water source during a normal tidal cycle, (2) the period of time that this average condition existed, and (3) the flow rate through a 36 inch pipe, 60 feet long and equipped with automatic flap gates. Calculations on the flow rate were based on the assumption that the pipe was set an an elevation which maximized the flow during a tidal cycle.

Photo 6. Asphalt coated corregated metal pipe with attached combination slide and flap gate used as tidal water control structure.

Photo 7. Above type of water control structure installed.

Photo 8. Redwood box type water control structure with flashboards commonly installed through interior levees for individual pond water control.

Photo 9. Pump installed for positive water control, independent of tides, particularly beneficial in draining.

After considering these factors, it was determined that a 36 inch pipe could pass 125 acre-feet of water with average head conditions in 10.7 days. This time period is compatible with the recommended water management schedule. The clubs were then rated as adequate or inadequate according to the cross-sectional area of existing openings (Plate 8). Those clubs with cross-sectional areas of pipe less than the area present in one 36 inch pipe per 100 acres flooded were considered inadequate. Clubs with areas equal to, or in excess of one 36 inch pipe per 100 acres flooded were considered adequate.

There were 40 clubs in the adequate category and 60 were rated as inadequate. If similar conditions existed on clubs that were not inventoried, then 86 clubs in the Marsh may have inadequate facilities. Bringing these inadequate facilities up to an adequate rating would require, on the average, the installation of one 36 inch pipe for each inadequate club.

Drainage

Drainage facilities are similar to flooding facilities; the same procedure used to determine pipe sizes for flooding was used for drainage. Inventory information indicated that the average opening available for drainage was 4.28 square feet per 100 acres flooded. This average is approximately equal to the flow area of a 30 inch pipe. The capacity of a pipe this size with an average head of 0.6 feet is 13 cubic feet per second. In January and February, with average tidal conditions, 20 hours during any 41 hours period have this average head. It is possible to drain 10.9 acre-feet of water during any 41 hour period. A 100 acre pond, flooded to a depth of 1.25 feet, can be drained in 19.6 days. Since the water management plan prescribes a drainage period of 20 days or less, the calculated drainage period based on one 30 inch pipe per 100 acres flooded is satisfactory. However, above average tides, common in the spring, will increase this drainage period, especially when flood flows are involved.

Clubs with less than a 30 inch pipe per 100 acres flooded were considered to have inadequate drainage facilities. There were 36 clubs out of 99 that had inadequate drainage facilities. From this, it was estimated that a total of 53 clubs would require additional drainage facilities to bring them up to standard (Plate 9).

Spreader Ditches

Spreader ditches facilitate the distribution of water after it passes through a levee. The presence of these ditches increases the efficiency of flooding and drainage operations and makes it possible to more effectively leach salts from the soil.

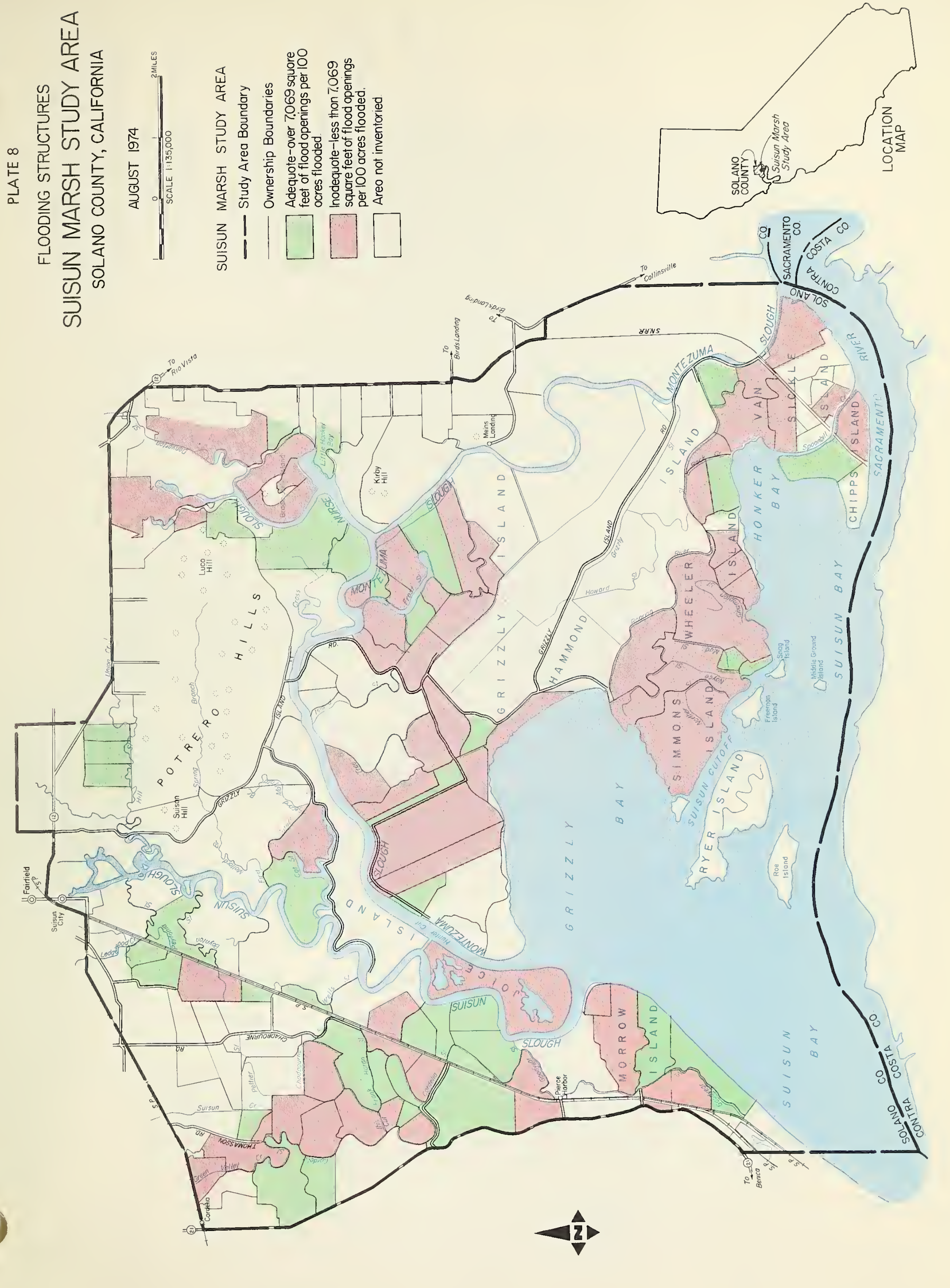


PLATE 8
FLOODING STRUCTURES
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA
AUGUST 1974
SCALE 1:135,000
0
2 MILES
SUISUN MARSH STUDY AREA
Study Area Boundary
Ownership Boundaries
Adequate-over 7,069 square feet of flood openings per 100 acres flooded
Inadequate-less than 7,069 square feet of flood openings per 100 acres flooded.
Area not inventoried
LOCATION MAP
SOLANO COUNTY
Suisun Marsh Study Area
SACRAMENTO CO.
CONTRA COSTA CO.
SOLANO
POTRERO HILLS
GRIZZLY ISLAND
HAMMOND ISLAND
WHEELER ISLAND
SIMMONS ISLAND
RYER ISLAND
CHIPPS ISLAND
VAN SICKLE ISLAND
JOICE ISLAND
MORROW ISLAND
GRIZZLY BAY
HONKER BAY
SUISUN BAY
MONTEZUMA SLOUGH
SUISUN SLOUGH
NURSE SLOUGH
SACRAMENTO RIVER
SUISUN CUTOFF
Fairfield
Suisun City
Cordelia
Pierce Harbor
Meins Landing
Kirby Hill
Luco Hill
Suisun Hill
Snag Island
Middle Ground Island
Freeman Island
Roe Island
To Rio Vista
To Birds Landing
To Collinsville
To Benicia
CHADBOURNE RD.
THOMASSON RD.
GRIZZLY ISLAND RD.
SNRR
S.P.

Information on spreader ditches was obtained for 100 of the 109 clubs inventoried. These 100 clubs had an average of 30 lineal feet of spreader ditch per acre. A subjective rating of good, fair or poor was assigned based on the general knowledge that clubs with good ratings had the capability of circulating water more efficiently (Plate 10). Clubs with 20 lineal feet of ditch per acre or less were rated poor, clubs with 20 to 40 lineal feet per acre were considered fair, and clubs with ditches in excess of 40 lineal feet per acre were rated as good.

The following estimates are based on the assumption that the average spreader ditch was 3 feet deep, had a bottom width of 3 feet and had 2 to 1 side slopes. It is estimated that 460,000 cubic yards of fill must be excavated to bring all clubs inventoried (109) up to an average of 40 lineal feet of spreader ditch per acre. Expanding this to include all clubs in the Marsh would require the excavation of 608,000 cubic yards of fill.

Water Circulation

In general, flooding and water management are for two purposes: (1) to provide ponds with a stable water level for duck hunting during the hunting season, and (2) to provide suitable waterfowl habitat. This latter objective is more difficult to achieve and requires close attention to water management, particularly when brackish water is used. It is desirable to prevent highly saline conditions from developing as a result of poor water management.

Three main types of water management systems were found to exist on clubs with seasonally flooded ponds. Each method was generally related to the physical nature of the club. It was apparent that some of the systems were well established and had been used for a considerable length of time.

The first method of water management consists of flooding from the high end of the club, distributing water through main and spreader ditches to the ponds, and finally draining through structures at the opposite (low) end of the club. This method was considered the most efficient and was rated as good (Plate 11, Pocket inside Cover).

The second method involves water entering through a structure at one end of the club, flowing by way of spreader ditches through the ponds, and eventually returning to a separate drainage structure at the same end of the club as the inlet. This method is not as desirable as the first because the placement of inlet and outlet structures at the same end of the club restricts water circulation and results in the accumulation of salts at the end of the club opposite the inlet and outlet structures. This method of water management was rated as fair (Plate 11).

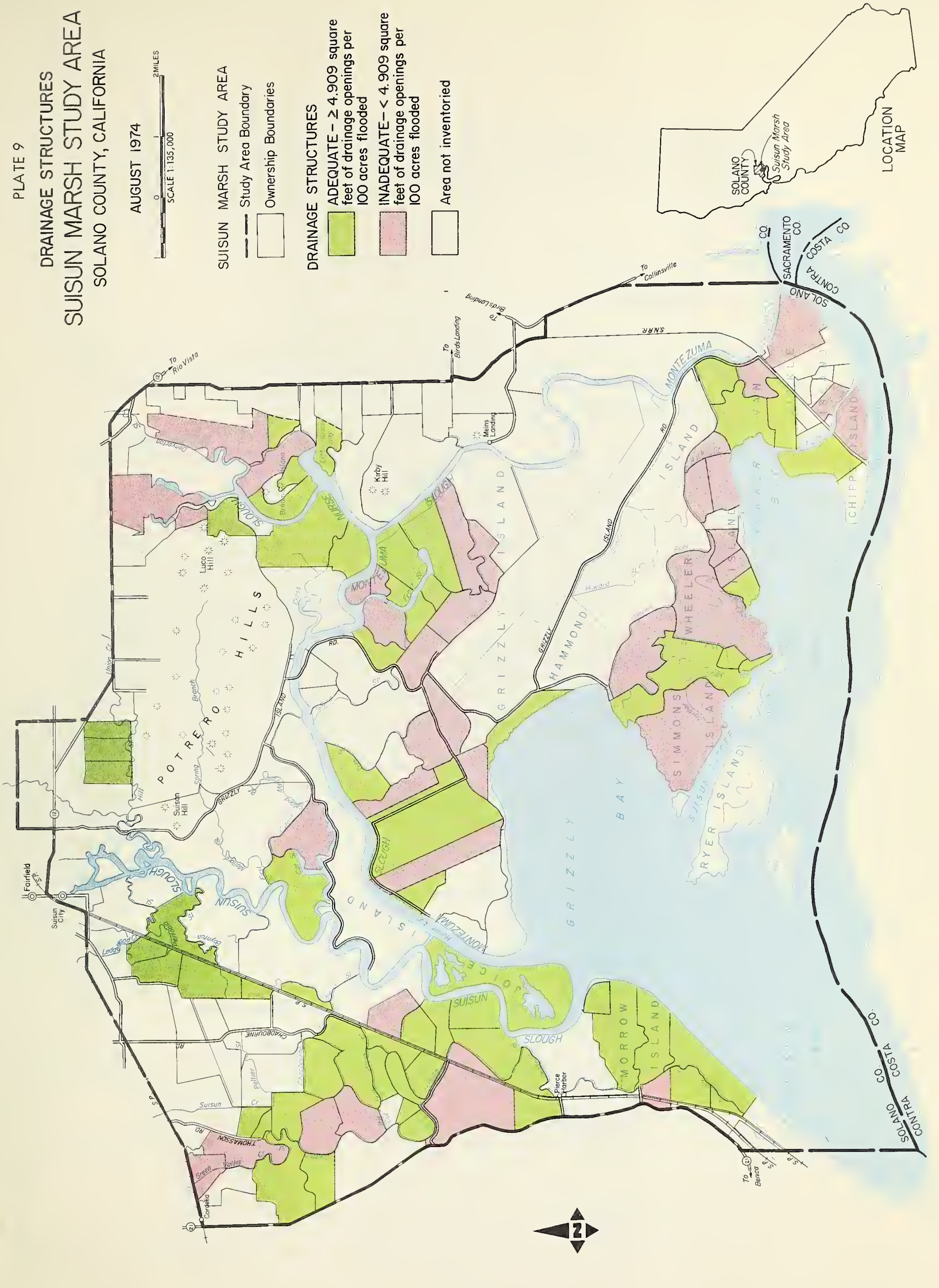


PLATE 9
DRAINAGE STRUCTURES
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA
AUGUST 1974
SCALE 1:135,000
0
2 MILES
SUISUN MARSH STUDY AREA
Study Area Boundary
Ownership Boundaries
DRAINAGE STRUCTURES
ADEQUATE – ≥ 4.909 square feet of drainage openings per 100 acres flooded
INADEQUATE – < 4.909 square feet of drainage openings per 100 acres flooded
Area not inventoried
SOLANO COUNTY
Suisun Marsh Study Area
LOCATION MAP
SACRAMENTO CO.
CONTRA COSTA CO.
SOLANO CO.
To Rio Vista
To Birds Landing
To Collinsville
Meins Landing
Kirby Hill
Luco Hill
Suisun Hill
POTRERO HILLS
GRIZZLY ISLAND
HAMMOND ISLAND
WHEELER ISLAND
SIMMONS ISLAND
RYER ISLAND
CHIPPS ISLAND
VAN SICKLE ISLAND
MORROW ISLAND
GRIZZLY BAY
MONTEZUMA SLOUGH
NURSE SLOUGH
SUISUN SLOUGH
Fairfield
Suisun City
Pierce Harbor
Cordelia
To Benicia
THOMASSON RD.
CHADBOURNE RD.
GRIZZLY ISLAND RD.
S.P.
SN.R.R.

The least desirable method of water management involves flooding and draining through the same structure. This method precludes water circulation and offers almost no opportunity for water or soil salinity control. This method was rated as poor (Plate 11).

MANAGEMENT PRACTICES

Water Management

The type of habitat developed is related more to water management than any other single factor. The inventory of private duck clubs in Suisun Marsh indicated there were seven types of water management schedules used.

The first type described (Type 1) is the water management schedule recommended by the Suisun Resource Conservation District, Soil Conservation Service and California Department of Fish and Game. It was developed by SCS and the Department of Fish and Game and approved by the Solano County Mosquito Abatement District. This water management schedule is as follows:

Type 1. Flood in October as rapidly as possible so that the water level desired for hunting (shooting level) is reached by the first day of the waterfowl hunting season. (Circulate water through main channels for one month prior to flooding to reduce salinity levels and to eliminate danger of damaging fish populations).

Circulate with inlet gates set to allow maximum quantities of water to flow through all ponds during the season, holding the water at shooting level.

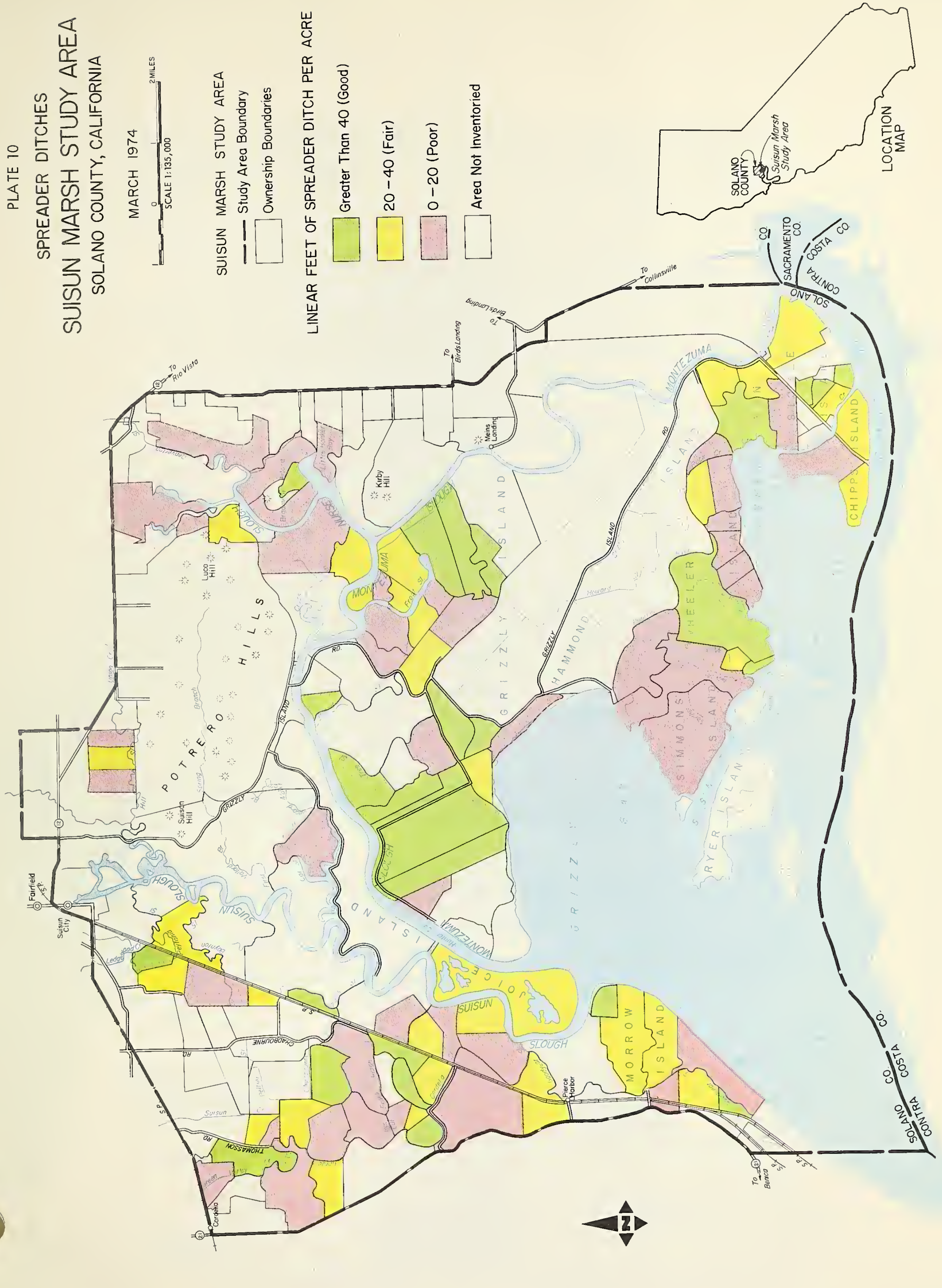
Drain on the last day of hunting. Close the inlets, open the outlets, and allow club to drain as quickly as possible.

Flood as soon as the ponds are drained. Open the inlet and allow the water to raise nearly to shooting level.

Drain all surface water again as quickly as possible. This flood-drain cycle should be repeated two or three times, depending on weather conditions, to flush toxic salts out of the surface layer of the soil.

Flood so that by the first of April water levels are stabilized with an average of three to six inches of water over the majority of the pond areas.

Circulate by setting the inlet gates and outlet gates to allow maximum quantities of water to flow



U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE USDA-SCS-PORTLAND, OREG 1974

M7-PL-23249-12

through all ponds. EXTREME CARE must be taken to eliminate fluctuation of the water which would allow production of large numbers of mosquitoes.

Drain during the first week of June, when the majority of alkali bulrush and other waterfowl food plants have set seed. Close the inlets, open the outlets, and allow complete drainage.

All ponds will now dry and growth of cattails, tules and other undesirable plants which require water will be retarded. This also will allow time during August and September for necessary maintenance of water control structures, blinds, and ditches and mowing of pond areas for a successful hunting season.

A graphic representation of this water management schedule and those which follow is presented in Figure 9.

The other six types of water management are as follows:

Type 2. Ponds flooded to shooting level prior to duck season, inlet and outlet gates set to circulate water throughout the season, ponds drained at the end of the waterfowl season usually in mid-January, followed by one flood-drain cycle. The club is then dried up until the following season.

Type 3. Ponds flooded to shooting level prior to duck season, inlet and outlet gates set to circulate water throughout the season, circulation continued for three weeks to one month after the end of the hunting season. Ponds are then drained and left to dry.

Type 4. Ponds flooded to shooting level prior to duck season, water is circulated throughout the season, and then drained at the end of the season and left to dry.

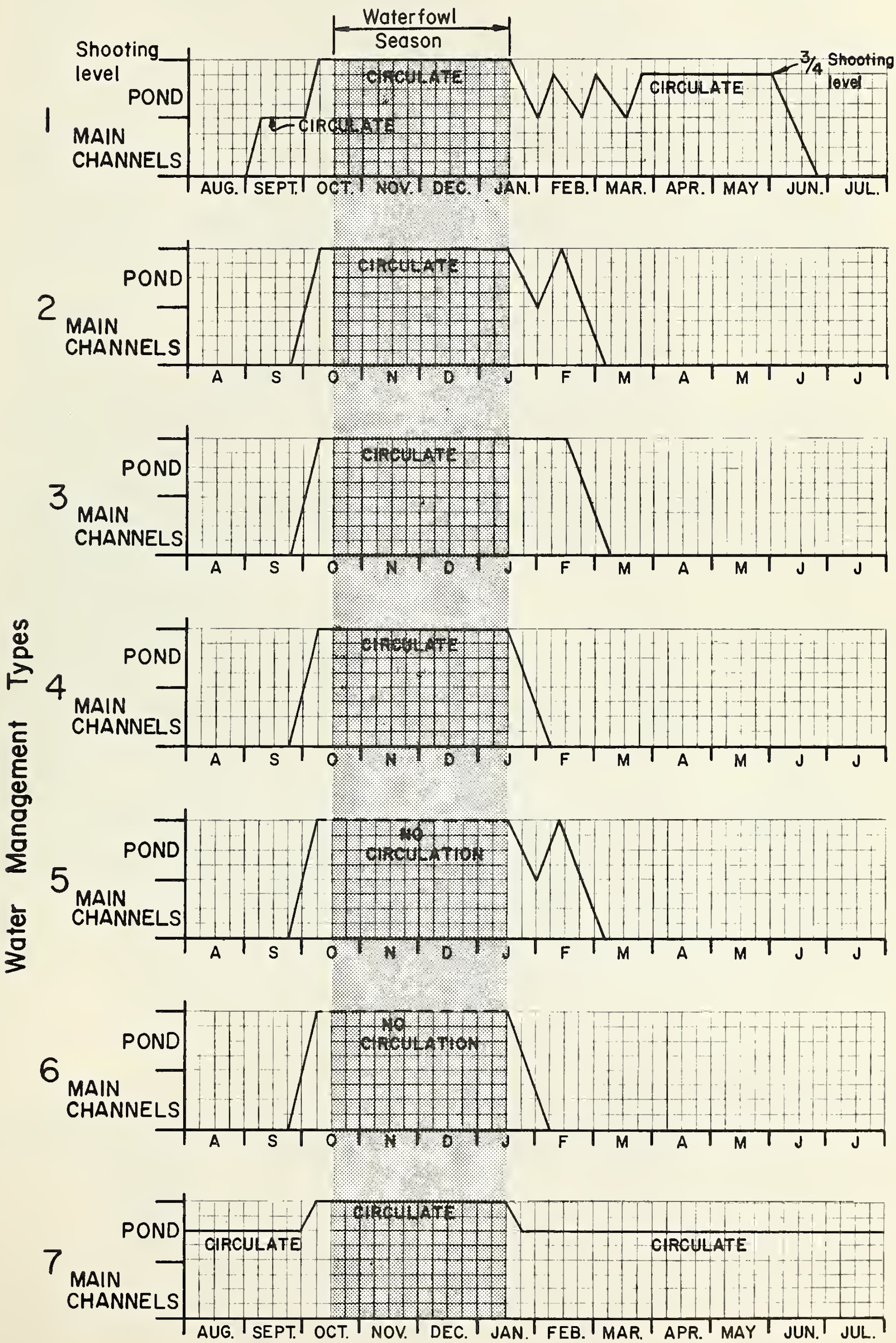
Type 5. Ponds flooded to shooting level prior to opening of season, water levels maintained with no circulation, drained at the end of the season, followed by one flood-drain cycle, the club is then allowed to dry up.

Type 6. Ponds are flooded to shooting level prior to opening of season, water levels maintained with no circulation, drained and allowed to dry up after the end of the season.

Type 7. Ponds are permanently flooded on a year-round basis. Water levels may be dropped some after the end of the hunting season, but water is circulated through the ponds continuously.

Three of the above types of water management are used more

Figure 9
WATER MANAGEMENT SCHEDULES USED BY PRIVATE DUCK CLUBS IN SUISUN MARSH



frequently than the others: Types 1, 4, and 6 (Table 14 and Plate 12). The most frequently used type of water management was Type 4, where water is circulated during the season and then drained at the end of the season. This type was used by 53 out of the 109 clubs. Generally the physical facilities present on these clubs would make conversion to Type 1 management a simple matter. The second most frequently used type of water management is the recommended Type 1. As more conservation plans are developed, this number will increase. Conservation plans were developed for 10 duck clubs during 1973. Most of these clubs planned to begin managing their water as in Type 1 that year; others planned to install needed water control structures and ditches before they could follow this schedule. Type 6 water management was being used by 19 clubs.

TABLE 14
WATER MANAGEMENT SCHEDULES FOR
100 PRIVATE DUCK CLUBS INVENTORIED
IN THE SUISUN MARSH DURING 1973

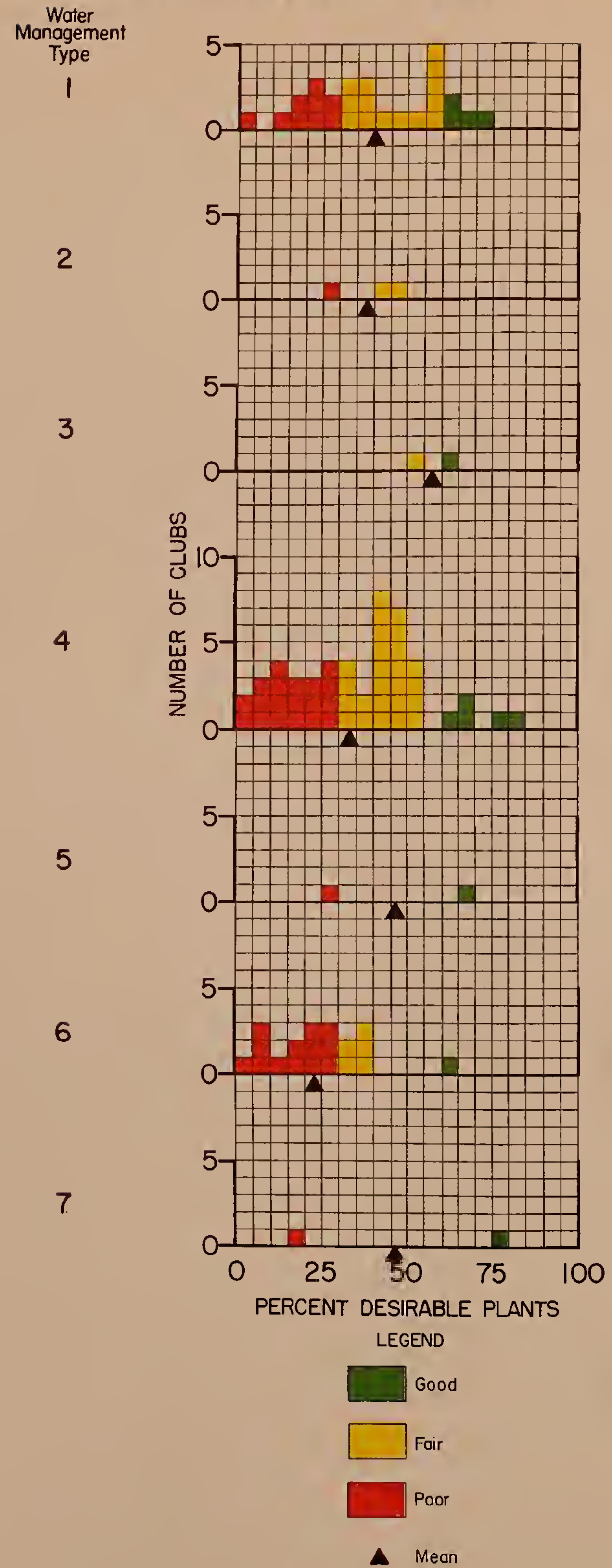
WATER MGT. SCHEDULE	NUMBER OF CLUBS USING WATER MANAGEMENT TYPE BY GROUP						
	I	II	III	IV	V	VI	TOTAL
1	1	5		2	11	8	27
2	1		1	1	1		4
3	2						2
4	16		9	4	12	12	53
5	1				1		2
6	4	6	2	1	3	3	19
7	2		1		1		4
TOTAL BY TYPE	27 1/	11	13 1/	8	29	23	111
TOTAL CLUBS	26	11	12	8	29	23	109

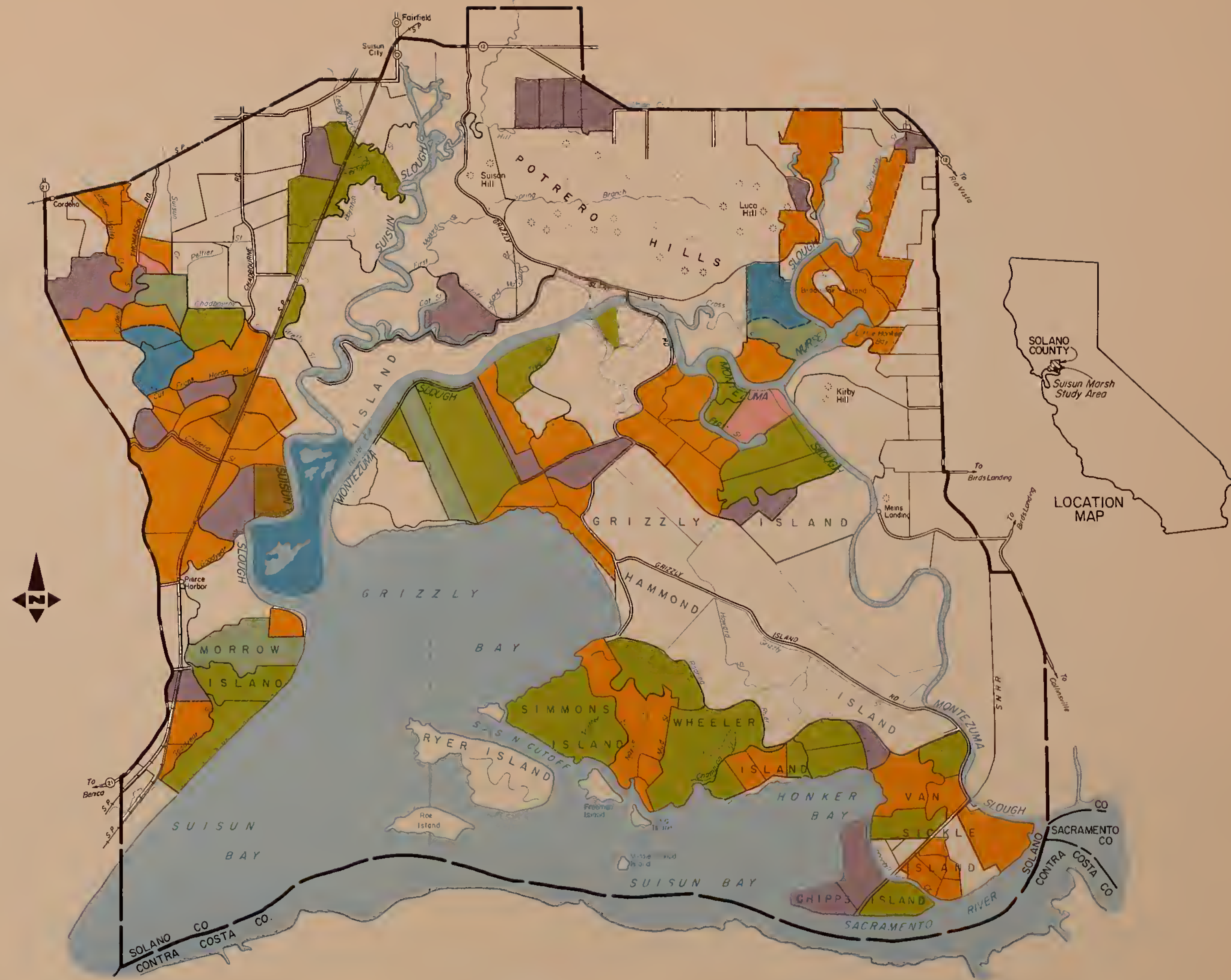
1/ Group has one club with two types of water management.

Other Management Practices

Various methods of management are used in developing wetland habitat on duck clubs. Manipulation of water was the primary means

PERCENT DESIRABLE PLANTS BY WATER MANAGEMENT SCHEDULE





SUISUN MARSH STUDY AREA

- Study Area Boundary
- Ownership Boundaries

WATER MANAGEMENT SCHEDULES

1 Follow SCS schedule
2 Flood, circulate, drain; Flood & drain
3 Flood, circulate during & after season-drain
4 Flood, circulate, drain & dry
5 Flood, drain after season; flood & drain
6 Flood, drain & dry after season
7 Permanently flooded
Area not inventoried

PLATE 12

WATER MANAGEMENT SCHEDULES
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA

AUGUST 1974

0 1 2 MILES
SCALE 1:135,000

of influencing growth of vegetation to develop wetland habitat for waterfowl and waterfowl hunting, however a number of other management practices were used by some of the clubs inventoried. Their use has been summarized in Table 15. These methods are primarily concerned with establishment of plants, control of undesirable plant growth, and reduction of excessive plant growth.

TABLE 15

SUMMARY OF VARIOUS MANAGEMENT PRACTICES USED BY 109 PRIVATE DUCK CLUBS INVENTORIED IN SUISUN MARSH, 1973

		Management Practice (No. of Clubs)				
Group	Total Clubs	Seeding	Burning	Discing	Mowing	Herbicides
I	26	6	10	12	23	
II	11	5	3	2	8	
III	12	1	6	5	11	1
IV	8	1	2	4	6	
V	29	4	11	9	25	
VI	23	1	15	6	21	
Total	109	18	47	38	94	1
Percent	--	17	43	35	86	1

Twenty-one club managers tried seeding various plants which they felt would be desirable for waterfowl use. Many of these failed or produced poor results (Table 16) because they were not adapted to conditions found on the club, i.e. high salinity and low pH. Attempts at seeding alkali bulrush and barley met with better success than did milo, millet or watergrass. Alkali bulrush often established itself in Suisun Marsh without seeding when suitable conditions were created by proper water management.

TABLE 16

REPORTED RESULTS OF ATTEMPTS AT SEEDING VARIOUS PLANTS FOR HABITAT IMPROVEMENT BY DUCK CLUBS INVENTORIED IN SUISUN MARSH, 1973.

		Planting Success (No. of Clubs)			
Plant Species	Number of Clubs	Good	Fair	Poor	Failed
Alkali bulrush	8 1/	4	1	1	1
Barley	6	1	3	1	1
Milo	1	-	-	1	-
Millet	3	-	-	-	3
Water grass	3	-	-	2	1

1/ One club did not report plant success.

Numerous methods were used to check the growth of undesirable vegetation or eliminate excessive growth (Table 15). Controlled burning (Photos 10 and 11) was used by 43 percent of the clubs to retard growth of undesirable plants or remove rank vegetation. Discing was also used for these reasons and in a few cases to promote the establishment of desirable plant species such as fat hen, brass buttons, and alkali bulrush.

Discing was also used to break up mats of thick vegetation and sod. The loosened mats promote oxidation and thus subsidence. Also, when dry, this loosened material can be burned readily, thus reducing the accumulation of peat and effectively deepening the pond. Eighty-six percent of the clubs inventoried had used mowing as a management tool. This was mainly in the pond areas to provide open water (Photo 12) around the blinds for attracting waterfowl, placement of decoys, and to facilitate retrieval of birds by the hunter and his dog. Only one club reported using herbicides for vegetation control.

In general, most larger clubs employ caretakers who live on the clubs, primarily as a safeguard against pilferage. In addition, they often manage the club for its members. This usually entails opening and closing water control gates as needed and may include mowing ponds, repairing blinds and other general maintenance work. Most small clubs, on the other hand, do not employ caretakers and the management is dependent upon the amount of time club members are willing or able to spend on needed tasks. Often this is inadequate. In a few cases, a manager is employed to manage a group of clubs or a number of separated clubs. This

Photo 10. Using fire as marsh management tool.

Photo 11. A pond after being burned.

Photo 12. Pond being mowed to increase open water.

practice could be used by many of the clubs and could benefit Suisun Marsh as a whole.

RECREATIONAL USE

Most clubs in the Marsh were used primarily for waterfowl hunting. These clubs, on the average, had one set of blinds (single, double or triple) for every 21 acres of ponded area. Often there were two or more blinds per pond, however, only one blind was used, depending on weather or other conditions affecting the flight pattern of the birds and hunter preference. While there was only an average of 10 hunters per club, an undetermined number of guests usually hunted on most clubs.

Other recreational activities were noted. Among these were fishing, sight-seeing, bird watching, exercising or training dogs, water skiing and other outdoor activities such as barbecues. Sufficient data was not obtained on these activities to quantify their use but, in general, they contributed significantly to the recreational activities of many members, their families and friends.

VEGETATION

In an attempt to correlate management with plant species composition, vegetative surveys were conducted on 109 private duck clubs during 1973. Evaluation of these surveys, when summarized by natural subdivisions of the Marsh (Plate 2), produced the following generalizations which apply to groups of clubs:

Alkali bulrush was a major element averaging over 10 percent in all groups except Group III (Table 17). The average for clubs in Groups IV, V and VI tended to be higher with alkali bulrush comprising between 20 and 26 percent. The average amount of alkali bulrush on duck clubs in Group II and III was significantly lower, averaging only slightly more than ten and eight percent of the cover respectively.

Brass buttons occurred on many clubs in each group, but it was generally of only minor consequence. A few clubs did have significant amounts ranging as high as 19 percent. However, it should be noted that brass buttons, an early season plant, matured and dried up during the summer and was often concealed by other plants such as fat hen and pickleweed.

The small amount of fat hen in Group II may have been due to unfavorable conditions caused by (1) permanent or extended flooding, which promoted cattail growth and (2) early drainage with little or no flushing which resulted in excessive soil salinities.

Baltic rush was less abundant on the average in Group I and IV, the western side of the Marsh, than it was in the other groups (Table 17).

TABLE 17

PERCENT COMPOSITION OF MAJOR PLANT SPECIES FOUND ON 109 SUISUN MARSH DUCK CLUBS DURING THE SPRING AND SUMMER 1973

PERCENT OF GROUND COVER

Group	No. Clubs	Total Acres	Alkali bulrush	Brass buttons	Fat hen	Baltic rush	Pickleweed	Saltgrass	Upland grasses	Dock	Thistle	Radish	Sago pondweed	Cattail	Tule	Olney bulrush	Barley	Misc.	Bare Ground
I	26	6,156	16.0	3.9	15.3	1.7	17.9	8.2	10.8	2.8	0.2	0.5	3.0	4.8	2.9	2.0	0.3	3.2	6.4
II	11	2,298	10.1	4.6	9.1	5.5	17.3	14.8	14.9	4.1	0.1	0.1	0.5	8.9	3.8	3.5		1.9	4.2
III	12	3,183	8.3	0.1	1.9	3.7	10.9	9.5	10.6	0.1				21.7	22.4			3.8	6.8
IV	8	2,099	22.8	6.6	13.9	2.8	33.9	8.8	2.2	2.2				1.3	0.7			3.0	1.6
V	29	10,846	25.6	3.0	8.1	3.8	18.3	11.2	3.1	1.7	0.2	0.5	2.5	4.8	6.8	0.8		3.2	5.4
VI	23	5,424	25.6	1.6	10.4	5.0	10.1	3.7	1.4	1.0				12.7	17.8			6.0	3.3
Total	109	30,006																	
Average			20.4	3.0	9.8	3.7	17.0	9.2	6.0	1.9	0.1	0.3	1.6	8.1	9.0	1.2	0	3.7	5.0

Pickleweed was relatively abundant in all six groups (Table 17). However, in Group IV, an area of higher salinity, pickleweed was significantly more abundant. The seven inventoried clubs south of Suisun Slough had pickleweed cover ranging from 25 to 46 percent. Certain clubs in the other groups, except Group VI, have large stands of pickleweed. One area in Group I had 59 percent of the ground cover composed of pickleweed.

Saltgrass was least abundant in Group VI (Table 17), primarily because fresher water conditions allow other species to compete with it successfully. Also, the more extensively ponded areas and subsequent submergence inhibited growth of saltgrass.

Upland grasses were scarce except in Group II where large amounts occurred on unflooded areas scattered within the manageable land on three clubs (Table 17). Two of these clubs were used primarily for livestock grazing.

Sago pondweed was abundant in large ditches on many clubs but was particularly important on two clubs that were permanently flooded, one located in each of Groups I and V (Table 17).

Cattail and tule, normally associated with extended periods of flooding, were particularly abundant on clubs in Groups II and VI where they made up 44 and 30 percent of the vegetation, respecttively (Table 17).

Only four clubs planted barley and they were all located in Group I (Table 17). Bare ground was significant in all six groups averaging five percent of the surface area (Table 17). It was primarily associated with low pond bottoms lacking adequate drainage outlets.

On the manageable portions of the clubs inventoried, alkali bulrush was significantly more abundant than other plant species. It comprised 20 percent of the ground cover. Pickleweed was the next most abundant at about 17 percent, followed by cattail and tule combining to average nearly 17 percent. Fat hen and saltgrass each provided nearly 10 percent of the cover (Table 17).

VEGETATIVE SURVEYS

George, et. al., (1965) reported the results of a vegetation survey of the Suisun Marsh that was conducted in 1961. A similar survey was completed during the summer of 1973 as part of the Suisun Marsh Four Agency Study. The most recent survey was the subject of a preliminary report prepared by Harry George (1974) and is summarized in Table 18 along with data from the 1961 survey. These surveys covered the entire Marsh, including tidal and leveed areas as well as all private, state and federal lands. They indicate the major vegetation types found in the Marsh and their relative abundance as well as changes in abundance that have occurred during the intervening 12 year period.

TABLE 18

PERCENT COMPOSITION OF MAJOR PLANT SPECIES AND GROUPS MAKING UP THE GROUND COVER OF THE SUISUN MARSH.

COVER TYPE	SURVEY YEAR 1961 1/	SURVEY YEAR 1973 2/
Alkali bulrush	6.1	12.7
Brass buttons	2.1	3.6
Fat hen	2.0	7.4
Baltic rush	3.3	1.0
Pickleweed	24.9	24.5
Saltgrass	23.9	10.4
Olney bulrush	1.0	0.4
Cattail	4.5	2.6
Tule	5.4	14.6
Annuals 3/	8.8	9.4
Crops	8.0	7.7
Miscellaneous	7.6	0.4
Ponds	2.1	4.3
Bare ground	0.5	1.0

1/ George, et. al., 1965.

2/ Unpublished data supplied by George, 1974.

3/ Plants placed in annuals category were such plants as upland grasses, dock, thistle, and wild radish.

Estimates of the plant cover from the inventory on 109 private duck clubs (Table 17) included only the managed areas within the levees and therefore, are not completely comparable to the previously mentioned California Department of Fish and Game surveys. However, the data gathered for this report agree quite closely with information developed by Fish and Game.

There was a significant increase in the amount of alkali bulrush and fat hen, while brass buttons increased only slightly. Pickleweed changed very little and remained the most abundant single cover type. Saltgrass decreased in abundance while tules increased considerably. These changes can be largely attributed to better water management on the clubs during the past 10 years. The exception might be the increase in tules. Much of their increase may have occurred in the tidal areas, primarily around Grizzly Bay. It is encouraging to note that the most productive waterfowl food plants - alkali bulrush, fat hen and brass buttons - increased during the past decade from a total of 10 percent of the ground cover to 24 percent. This should indicate an increase in carrying capacity for ducks inspite of decrease in water quality during the same period.

EFFECT OF WATER MANAGEMENT ON PLANT GROWTH

It is felt that the excessive rains and overtopping of levees which occurred in December 1972 and January 1973 had some influence on the vegetation during 1973, being that some clubs were flooded longer than usual with fairly fresh water. However, the primary effect was an increase or decrease in plant vigor. Over the Marsh as a whole, changes in species abundance occurring from invasion of new areas was probably minimal. Decrease in plant vigor was apparent in some areas for plant species such as pickleweed and saltgrass which were adversely affected by extended submergence. The decrease in salinity resulting from the additional fresh water probably was the principal factor responsible for the increased vigor shown by fat hen and other plants such as watergrass and smartweed which are less salt tolerant.

Only three types of water management schedules (1, 4 and 6) had sufficient numbers of clubs represented to lend themselves to evaluation (Plate 12).

Looking at the 27 clubs which indicated they were using Type I water management, it was found that desirable plants made up an average of 39.6 percent of the ground cover. Rating these clubs, it was determined that 33 percent had poor habitat, 52 percent had fair and 15 percent had good (Plate 12). Alkali bulrush was the major species found on all clubs rated good using this type of water management.

The inventory reflects the habitat on a club at a given point in time and relates it to the type of water management the club was using at that time. Actually the habitat is a cumulative result of conditions over a long period of time. Major changes influenced by water management develop very slowly; therefore, a club which has only recently converted to the District's recommended method of water management will most likely reflect a small amount of change as compared to a club which has used the system over a long period of time.

Clubs using Type 4 water management had ground cover consisting of 34.0 percent of desirable plants on the average. Of these 53 clubs, 39 percent were rated poor, 51 percent fair and 10 percent good. On four clubs rated good, alkali bulrush was the dominant desirable plant. Fat hen dominated on the other club rated good.

The ground cover on the 19 clubs using Type 6 water management averaged only 23.2 percent desirable plants. Sixty-eight percent of these clubs had poor habitat, 26 percent were rated fair and only one club was rated as having good habitat. Fat hen was the dominate desirable plant on the club rated good.

Because of the small sample size and the influence of many variables a correlation between all water management types and plant species was not feasible (Table 19).

A relationship was apparent between water management and production of alkali bulrush when comparing Type 1, 4 and 6 water management schedules (Table 19). For the clubs using Type 1 management, alkali bulrush averaged 32 percent of the vegetative cover. Type 4 clubs had 17 percent and Type 6 had 12 percent of the cover in alkali bulrush. These data tend to substantiate that Type 1 management with existing water quality (water circulation and spring irrigation) enhances alkali bulrush growth.

A relationship between water management and production of fat hen was not apparent from the data (Table 19). However, it is felt that water circulation and drainage in early spring will promote fat hen growth, provided the soil salinity is low enough. On the other hand, the heavy growth of perennial plants may preclude the invasion and development of fat hen (See section on Marsh Ecology). The two clubs inventoried which used Type 3 water management produced large amounts of fat hen. In this type of management the water is circulated continuously through the season and up to one month after its close, then drained off. Discing and burning prior to initiation of this type of water management were additional management tools used by both of these clubs allowing invasion by fat hen, a heavy seed producing annual.

The growth of pickleweed is diminished by use of Type 1 management and enhanced by early drainage (Table 19). Prolonged sub-

TABLE 19

PERCENT OF VEGETATIVE COVER FOR VARIOUS
PLANT SPECIES BY WATER MANAGEMENT SCHEDULE

Water Management Schedule	Duck Clubs Inventoried	Average Percent of Cover[1/]					Average Club Size
		Alkali Bulrush	Fat-hen	Pickleweed	Saltgrass	Cattail and Tule	
1	27	32	11	15	7	14	342
2	3	26	11	32	5	6	443
3	2	7	35	12	3	13	274
4	52	17	11	21	13	16	208
5	2	25	6	12	9	7	187
6	19	12	8	20	11	15	198
7	2	16	0	5	5	20	454
Total[2/]	107	21	10	18	9	16	252

1/ Weighted by acreage in each club.
2/ Average percent cover is weighted average for all 107 clubs.

mergence will eliminate pickleweed. Water circulation may increase the competitive advantage for less salt tolerant plants.

Saltgrass growth is enhanced by early draining of the clubs (Table 19). This is a "meadow" plant which is salt tolerant. It requires some amount of drying of the soil and will not withstand extended periods of submergence.

Although the data indicates that cattail and tule growth were independent of the types of water management used in Suisun Marsh (Table 19), it is known that extended submergence promotes their growth. The lack of a relationship between water management and cattail and tule growth from the inventory data may be attributed to the fact that growth of these plants was most pronounced along the edges of ditches and permanent ponds where a more extended period of flooding is found. Salt tolerance is an important limiting factor as evidenced by low production in the more saline area of the Marsh, Group IV, and lack of cattail and tule in low, undrained pockets where water is present for extended periods but salt build-up occurs. In Group VI, where fresher water is available, cattail and tule growth does occur in the low pockets that do not drain readily.

It may reasonably be concluded from the data that use of the recommended water management schedule and system will eventually increase the amount of desirable plants in the Suisun Marsh, primarily alkali bulrush. It is believed that this system will eventually bring the habitat on a club to a desirable level, and once reached, adjustments may be necessary to maintain it at that level. It would be undesirable to develop alkali bulrush or any other food plant to the exclusion of all others or to allow alkali bulrush growth to develop to a point of such rankness or extent that considerable labor must be expended to open it up and make it more accessible and attractive to waterfowl. Similarly, in locations where fresher water is available, cattail and tule growth can reach an undesired level. Adjustment of the water management schedule periodically by shortening the extent of spring flooding can be an inexpensive means of controlling or preventing these conditions. By reducing the extent of spring flooding and thus extending the period of drying, areas of rank vegetative growth can be suppressed. Controlled burning can then be used to eliminate the excess vegetation and retard growth of these plants.

EVALUATION OF WATERFOWL HABITAT ON PRIVATE DUCK CLUBS

The primary value of Suisun Marsh has been its capacity to attract and hold waterfowl during the fall and winter. Therefore, waterfowl food production was considered as the most important element of the habitat, and the vegetation survey data was used as the basis for this evaluation. No correlation was apparent between the type of vegetation on 58 clubs and the ducks harvested per hunter day. So the basis for designating desirable or important plant species was made utilizing the results of food habits studies (George, et. al., 1965; Mall, 1969, and unpublished Department of Fish and Game data furnished by Bruce Browning).

To facilitate comparison of habitat produced to the type of management provided, only the portion of each club within the management unit (leveed area) was utilized. Three categories of ground cover were developed to evaluate the representative habitats.

The first category, Desirable Plant Species, was composed of plants considered to be the most important as a food source for the majority of waterfowl using Suisun Marsh. The plants included were alkali bulrush, barley, brass buttons, fat hen and sago pondweed.

The second category, Less Desirable Plant Species, included plants which generally are of a lesser value as food plants for waterfowl. These plants should not be construed as being without value as many provide an important food source for certain waterfowl species and a supplement for others. Some of them also provide protective cover and other uses beneficial to waterfowl as well as to many other forms of wildlife. The primary plants in this category are: pickleweed, saltgrass, cattail, tule and Olney bulrush. Also included are the plants listed as miscellaneous, some of which were abundant in specific locations but not in the Suisun Marsh as a whole. Examples are wild radish, thistle, dock and spurry. The last category included areas of bare ground.

Natural subdivisions of the Marsh (Plate 2) were used to obtain a more representative picture of typical conditions. It was felt that the source of water and type of management had a major influence on the habitat. Analysis by subdivision seemed more valid than attempting to hypothesize a typical club from the Marsh as a whole.

Clubs were rated by the amount of desirable plant species produced on them. Clubs with 30 percent or less of these plants were rated as having poor habitat, clubs in the 30 to 60 percent range were rated as fair and clubs with more than 60 percent of the cover in desirable plants were rated as good (Plate 13). Using the percent of desirable species as an indicator of condition some distinguishing characteristics were apparent for clubs in each of the groups.

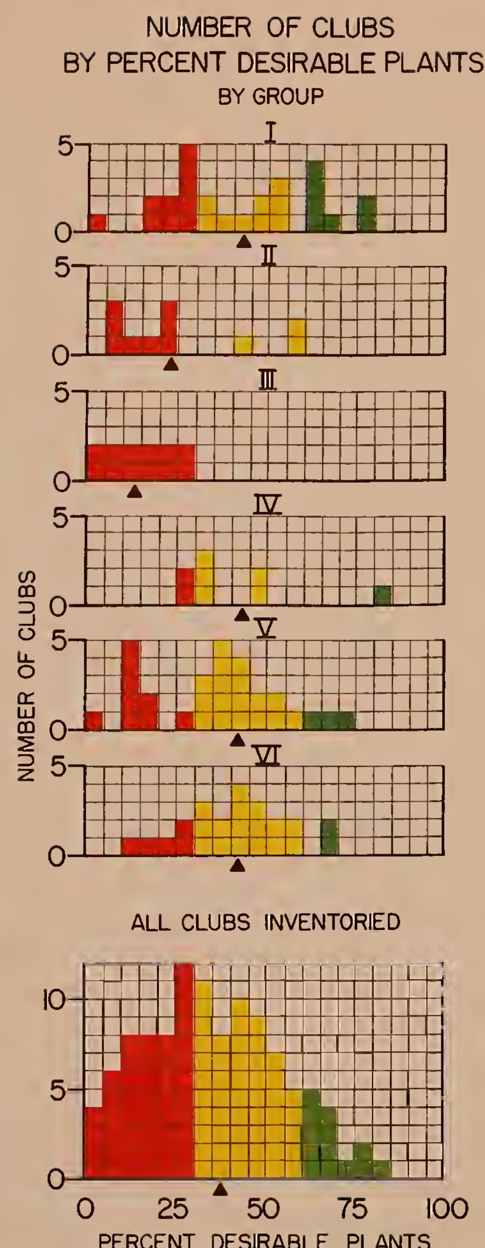
Clubs within Group II and III had disproportionately low amounts of desirable plants. The averages for clubs in these two groups were 24.3 and 12.8 percent respectively (Table 20). The averages for each of the other groups were above the mean, 37

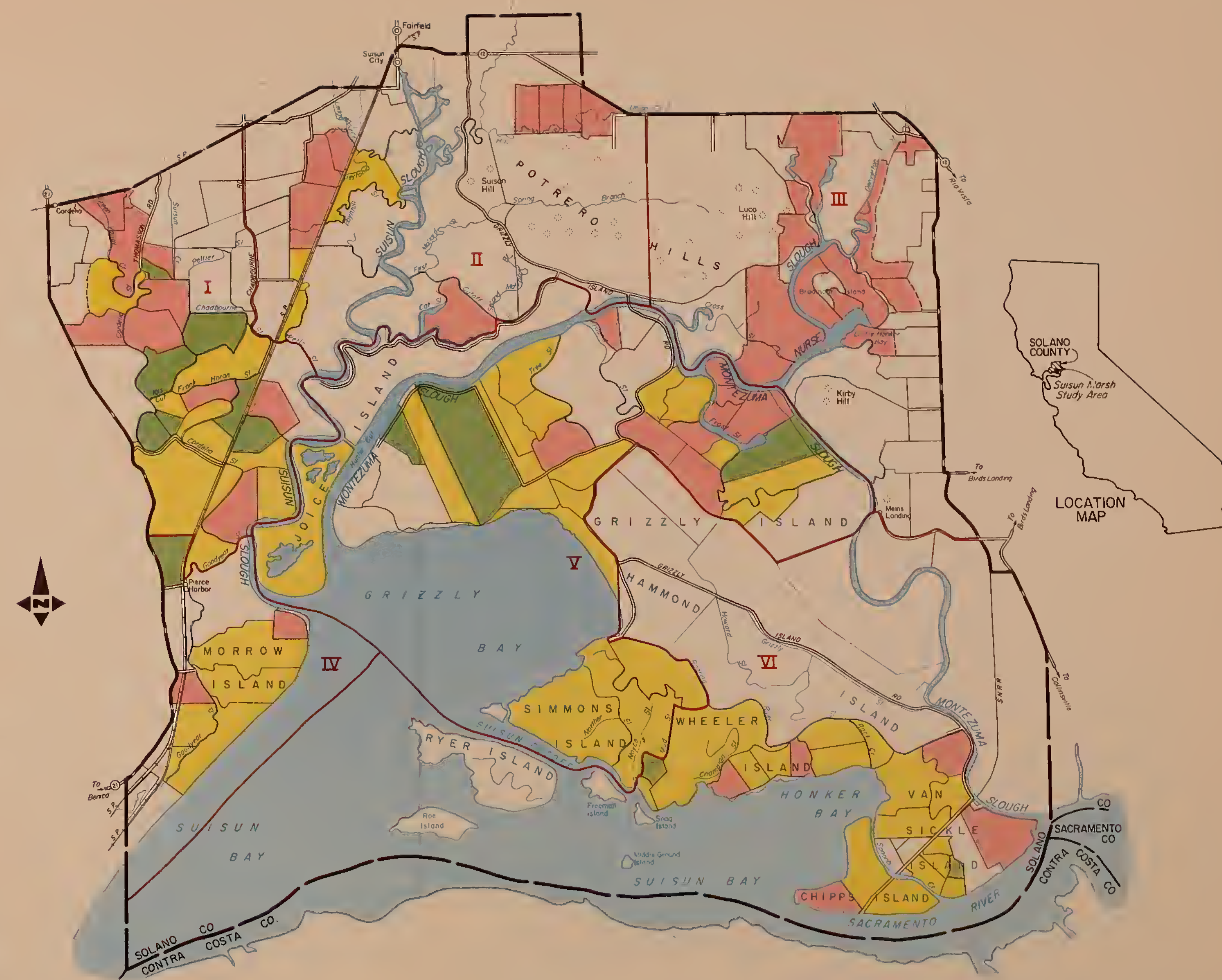
TABLE 20

AVERAGES OF DUCK CLUB SIZES AND VEGETATION FOUND FOR SIX GROUPS IN THE SUISUN MARSH

Group	Number of Clubs	Total Acres	Average Club Size	Percent Desirable Plants*	Percent Less Desirable Plants	Percent Bare Ground
I	26	5,819	224	40.6	52.6	6.8
II	11	2,223	202	24.3	71.5	4.3
III	12	2,424	202	12.8	78.5	8.7
IV	8	2,100	262	41.7	56.8	1.5
V	29	10,154	350	40.9	53.0	6.2
VI	23	5,169	225	40.4	56.2	3.4
Total	109	27,889				
		Average	256	37.0	57.5	5.5

* Desirable plants include alkali bulrush, barley, brass buttons, fat hen, and sago pondweed





LEGEND

- Good
- Fair
- Poor
- ▲ Mean

SUISUN MARSH STUDY AREA

- Study Area Boundary
- Ownership Boundaries

PERCENT DESIRABLE PLANTS

- Survey Group Boundary
- I Survey Groups
- 60% + (Good)
- 30-60% (Fair)
- 0-30% (Poor)
- Not Inventoried

PLATE 13

PERCENT DESIRABLE PLANTS

SUISUN MARSH STUDY AREA

SOLANO COUNTY, CALIFORNIA

AUGUST 1974

SCALE 1:135,000 — 1, 0, 1, 2 MILES

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

M7-SN-23249-7

percent desirable plants, for all 109 clubs inventoried in the Marsh (Table 20, Plate 13).

The examination of duck clubs in the individual groups in regards to their distribution and types of habitat (Plate 13), illustrates the complexity of the areas and some basic distinctions that can be made between them.

Group I had a large mixture of habitat conditions which varied significantly from one club to the next. Ten of the 26 clubs inventoried in this group were classified as having poor habitat, nine were fair and seven were good (Plate 13). The plant species which comprised 25 percent or more of the ground cover on individual clubs varied from club to club (Plate 14).

In Group II, eight clubs are classified as poor and three as fair. None of the clubs inventoried had greater than 60 percent desirable plants. The four clubs located on Hill Slough were managed primarily for livestock grazing. On two of these clubs, saltgrass made up more than 25 percent of the vegetation and upland grasses contributed largely to the ground cover (Plate 14). Pickleweed covered more than 25 percent of the ground on two other clubs in this group. In general, the clubs in this group had a large mixture of plants, most being of the less desirable types.

All 12 clubs in Group III were classified as having poor habitat. On eight clubs, cattail and tule made up more than 25 percent of the vegetation. Pickleweed and saltgrass were the major vegetative components on five clubs. None of the desirable plants made up greater than 25 percent of the vegetation on any of the clubs.

Five clubs in Group IV had fair habitat, two were classified as poor and one as good. On all seven clubs inventoried south of the mouth of Suisun Slough, where it empties into Suisun Bay, pickleweed comprised more than 25 percent of the vegetation. Alkali bulrush was also abundant and made up more than 25 percent of the vegetation on three of these clubs. The West Family Club which obtains water from Goodyear Slough had the largest percentage of desirable plants of any club in the Marsh. The percent composition of plant species on the West Family Club included alkali bulrush 48 percent, brass buttons, 18 percent, and fat hen, 18 percent, for a total of 84 percent desirable plants.

Most of the clubs in Group V were classified as fair or poor (Plate 13). Alkali bulrush, fat hen, pickleweed, and saltgrass were the most common plants (Plate 14). Pickleweed and saltgrass were abundant, though not exclusively, on clubs where cattle grazing influenced management.

Nearly 70 percent of the clubs inventoried in Group IV were classified as having fair habitat (Plate 13). The most abundant plants found on the clubs in this group were alkali bulrush, cattail and tule (Plate 14).

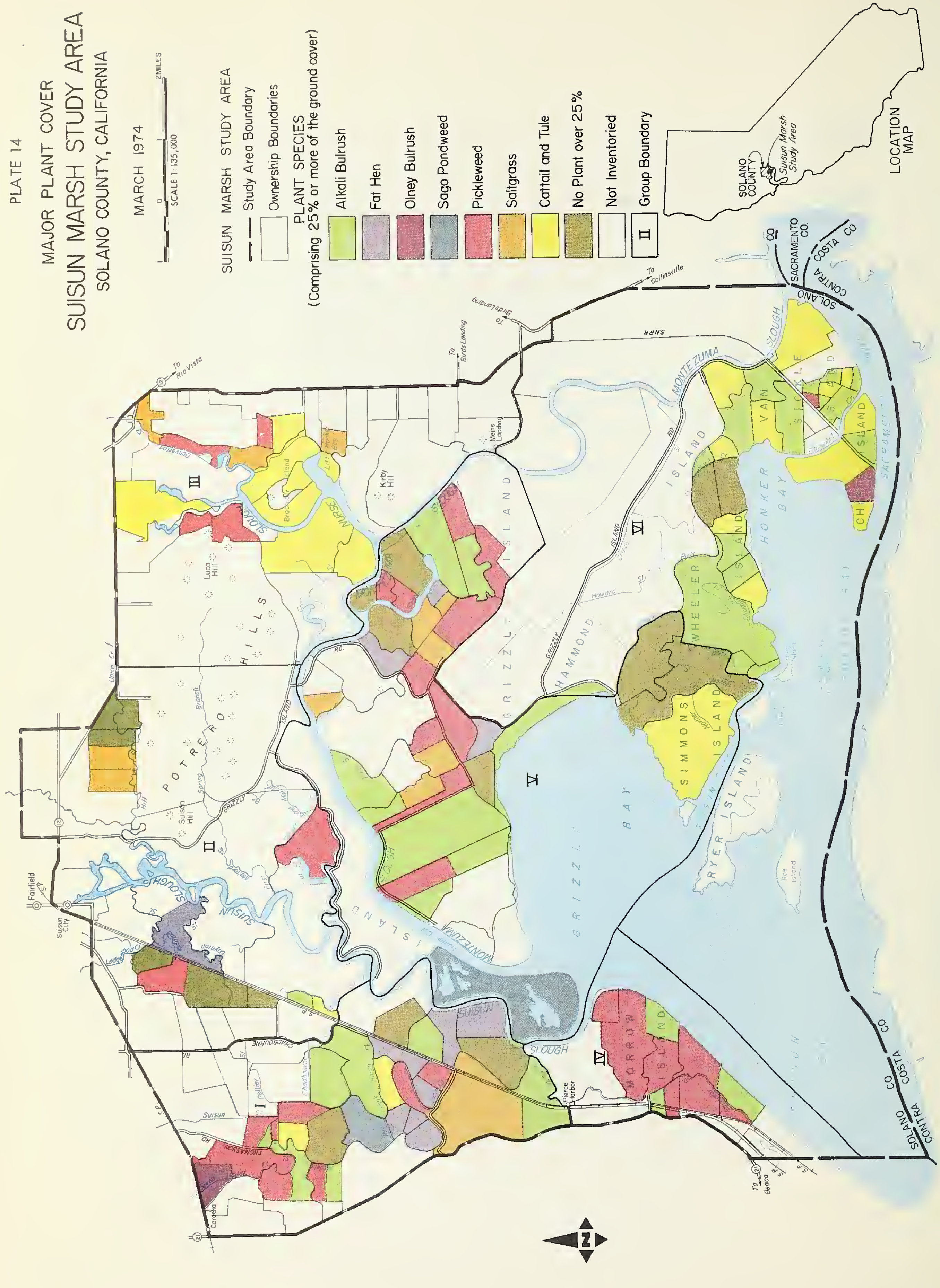


PLATE 14
MAJOR PLANT COVER
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA
MARCH 1974
SCALE 1:135,000
2 MILES
SUISUN MARSH STUDY AREA
Study Area Boundary
Ownership Boundaries
PLANT SPECIES
(Comprising 25% or more of the ground cover)
Alkali Bulrush
Fat Hen
Olney Bulrush
Sago Pondweed
Pickleweed
Saltgrass
Cattail and Tule
No Plant over 25%
Not Inventoried
Group Boundary
LOCATION MAP
SOLANO COUNTY
Suisun Marsh Study Area
SACRAMENTO CO.
CONTRA COSTA CO.
SOLANO
GRIZZLY BAY
HONKER BAY
SUISUN SLOUGH
MONTEZUMA SLOUGH
GRIZZLY ISLAND
SIMMONS ISLAND
WHEELER ISLAND
VAN SICKLE ISLAND
RYER ISLAND
MORROW ISLAND
POTRERO HILLS
Fairfield
Suisun City
Cordelia
Pierce Harbor
To Benicia
To Rio Vista
To Collinsville
To Birds Landing

Two important conditions stand out when comparing the area of Suisun Marsh which normally has fresher water to that which receives more saline water. In Group VI, where the fresher water occurs, alkali bulrush, cattail and tule are the most abundant plants (Plate 14), whereas, in Group IV, alkali bulrush and pickleweed are predominant. Alkali bulrush will tolerate both fresh and brackish water conditions. Cattail and tule prefer a fresh and/or extended flooded condition as found in Group VI where salinity is not sufficient to allow effective competition by alkali bulrush. In Group IV, the salinity is too high for cattail and tule without extended periods of flooding but it is fresh enough for alkali bulrush. Higher salinity and a limited period of submergence is advantageous to pickleweed.

Considering all the clubs inventoried, 13 had good habitat, 50 were rated fair and 46 were poor (Plate 13).

WATER CONTROL MANAGEMENT

PRESENT CONDITIONS

This section describes costs associated with existing facilities, their deficiencies and needed improvements under present conditions. The physical inventory information was preliminary in nature and the majority of this material was observed rather than measured. Consequently, the physical inventory and cost estimates derived from it can only be considered as rough approximations of values which might be revealed by a more detailed investigation.

The physical inventory information considered levees, water control structures, ditches and type of water manipulation based on placement of inlets and outlets. An attempt was made to evaluate each of these factors from the standpoint of existing structures, what the minimum standards should be for a well organized facility (Appendix 3) and what is needed to bring every club up to those standards utilizing present water sources and water quality. A summary of needed facilities and costs is presented in Table 21.

In order to determine the facilities needed to utilize water under present conditions or with a supplemental source of water, it was necessary to determine the total amount needed annually, distribution of use and peak flow needed. This information was obtained by determining the total amount of water required annually under present conditions, based on the use of the recommended water management plan.

TABLE 21

SUMMARY OF NEEDED IMPROVEMENTS

ITEM	QUANTITY	COST	COST/MILLION DOLLARS
Levees (outside)	1.4 m.c.y.*	2.00/c.y.	2.8
Levees (inside)	0.9 m.c.y.	1.00/c.y.	0.9
Inlets	86 pipe & gates	$4,000 ea.	0.4
Outlets	53 pipe & gates	$4,000 ea.	0.2
Spreader Ditches	.6 m.c.y.	2.00/c.y.	1.2
Revised Water Circulation Facilities	130@	$2,300	0.3
			5.8
Plus 15% escalation and contingencies			1.7
			7.5

* Million cubic yards.

It was first necessary to set up a water use schedule which included water to fill (1) the ditches, sloughs (inside the levees) and ponds, (2) water to saturate the soil profile under sloughs, ditches, and ponds, (3) water used by plants (consumptive use), (4) water lost by evaporation, and (5) water required for circulation to control salinity. These several items constitute the gross water required. The net water required is found by reducing the above by the direct rainfall occurring on the Marsh and the runoff from adjacent land around the Marsh that drains directly into the ponded areas. Runoff through the channels that flows through the area was not considered as adding water to the system. However, this water, by improving quality in tidal sloughs, is available for circulation.

Ponds cover an area of 32,900 acres and, at shooting level, have an average depth of 1.25 feet requiring approximately 41,100 acre-feet of water to fill them. The recommended water depth during the part of the season from January 15 to May 31 is three-fourths that of shooting level; therefore, the ponds during this period contain about 30,800 acre-feet of water.

Ditches cover 3,000 acres and water averages 3 feet in depth during the shooting season; they would contain about 9,000 acre-feet of water. During the rest of the time that water is being used, (January to June) the ditches contain about 8,250 acre-feet.

The sloughs cover 1,200 acres and the average water depth is about 6 feet deep. They contain about 7,200 acre-feet during hunting season. During the rest of the year, they are about 5 3/4 feet deep and contain about 6,900 acre-feet.

Another determination made was that of the quantity of water required to saturate the soil profile. It was assumed, based on limited observation, that: (1) at the beginning of flooding, mid-September, the soil profile was at its driest, (2) a water table existed at about 3 feet below the ground surface at this time of year, (3) the average soil from the standpoint of the amount of water required for saturation was mucky clay which had a dry weight of about 70 pounds per cubic foot, (4) the amount of water required for saturation (by weight per cubic foot) was 45 percent in the surface foot, 38 percent in the second foot, and 25 percent in the third foot, because of the close proximity of the water table, and (5) once the top three feet were saturated, water reaching the water table would not move laterally to any great extent. Therefore, 75.6 pounds or 1.2 cubic feet of water would be needed per square foot of surface soil flooded to saturate the soil profile. Thus, 37,100 acres (32,900 in ponds plus 4,200 in ditches and sloughs) would require 44,000 acre-feet of water.

Table 22 shows the monthly evaporation, transpiration, and rainfall amount. Values in this table are from "Climatologic Data" reports for California using the Grizzly Island Station for evaporation and precipitation amounts. The amount of consumptive use by plants was estimated, based on the Blaney-Criddle Formula and other data (SCS, 1967).

The last quantity evaluated was the amount of water required to maintain the ponds during the period they were flooded - October through May - replacing water lost through evaporation and transpiration plus that needed for salinity control. This was done in three steps.

The first step was to determine the average or representative water quality available for use in the Marsh under present conditions. This involved the analysis of water quality records collected throughout the Marsh at various points and at monthly intervals. (Unpublished data furnished by the Bureau of Reclamation). The salinity recorded in Cordelia Slough at Cygnus Station (S-33) was considered to be the most representative. Table 23 summarizes the water quality for this site. These data were used in formulating a water use schedule for the Marsh.

As stated earlier, the soil salinity in the root zone was most critical in the spring during May, where alkali bulrush was

TABLE 22

EVAPORATION LOSS, CONSUMPTIVE USE AND RAINFALL 1/
IN THE SUISUN MARSH

Month	Pan Evaporation (Inches)	Consumptive Use by Marsh Plants (Inches)	Rainfall (Inches)
January	1.22	1.22	6.44
February	1.63	1.58	4.75
March	3.37	2.05	1.38
April	6.71	6.30	0.37
May	8.48	7.00	0.24
June	10.31	(Ponds are dry)	0.12
July	10.77	"	0
August	9.00	"	0
September	6.70	5.00	0.32
October	3.76	3.15	1.42
November	1.86	1.00	4.17
December	0.95	0.35	4.25

1/ Based on USDC Weather Bureau data and Technical Release No. 21 (SCS, 1967).

TABLE 23

STATION S-33 QUALITY OF SLOUGH WATER IN MILLIMHOS ELECTRICAL CONDUCTIVITY

	1964-65 (Avg.)	1965-66 (Avg.)	1966-67 (Avg.)	1967-68 (Avg.)	1968-69 (Avg.)	1969-70 (Avg.)	1970-71 (Avg.)	Combined 7 Year Average	Approximate Parts Per Thousand
September	2.5	6.8	4.0	7.0	4.0	9.3	1.5	5.0	3.2
October	3.9	3.9	2.5	7.7	1.6	5.5	2.5	3.9	2.5
November	3.8	7.8	4.1	9.0	4.7	5.1	5.0	5.6	3.6
December	2.7	3.0	4.1	9.5	5.8	1.4	4.0	4.4	2.8
January	---	1.4	3.8	2.0	1.4	0.7	1.6	1.8	1.2
February	---	---	---	---	---	---	---	---	---
March	2.3	2.2	0.9	2.1	1.0	1.0	1.0	1.5	1.0
April	4.0	2.2	---	1.1	1.1	0.9	1.3	1.8	1.1
May	7.5	3.2	9.4	4.4	2.0	5.6	1.4	4.8	3.1

the key species desired. Therefore, the second step was to determine the amount of water necessary, using tidal water similar in salinity to that of S-33 to maintain a pond water salinity that would be less than 13.5 mmhos E.C. (9 0/00) during May (Mall, 1969).

The third step was to construct a water management schedule that accomplished the objective of providing desired water quality in the ponds during May.

With the ponds filled to capacity for the hunting season, enough water should be introduced during the period from October 15 to January 15 to: (1) replace water lost to evaporation and consumptive use with water of a high enough quality to re-dilute the salt concentrated during the evaporation and transpiration processes and (2) circulate water through the ponds to improve the quality of water which had been applied during initial flooding, since this water is obtained during the low flow period of the year when water quality is at its poorest.

From the period of January 15 to May 30, the following conditions usually exist: (1) During the last 15 days of January the water quality improves and good quality water lasts through February. Therefore the ponds should be drained completely and refilled at least twice to reduce the salt load in the ponds. Water required for the evaporation and transpiration losses is negligible at this time of year. (2) During the latter part of March and through April the water quality usually starts to deteriorate. As quality deteriorates, only enough circulation water should be added to maintain the water level. During those years when slough water is of good quality, a maximum amount of circulation should be used during the month of April for maximum salt reduction. (3) Tidal water quality during May is historically poor, particularly during the latter part of the month, hence no circulation water should be used. Only enough water should be added to compensate for losses.

The foregoing has been summarized in Table 24 as a generalized operation schedule for seasonally flooded ponds using present water quality. Information on the relationship between quality of applied water, water in ponds and pond soil salinity is sketchy at the present time. Therefore, the above schedule was developed from estimated relationships derived from data obtained by Mall (1969) and SCS, as shown in Figure 10.

For each month the ponds were flooded, the average salinity of the tidal water available was indicated along with salinity levels that could be expected in the ponds. The third column presents the estimated soil salinity that would prevail if this water management schedule were followed closely. Generally pond soil salinity was 2.2 times that of the pond water. The last column indicates the water management activity to be accomplished each month or part of a month. The two principle objectives were to

TABLE 24

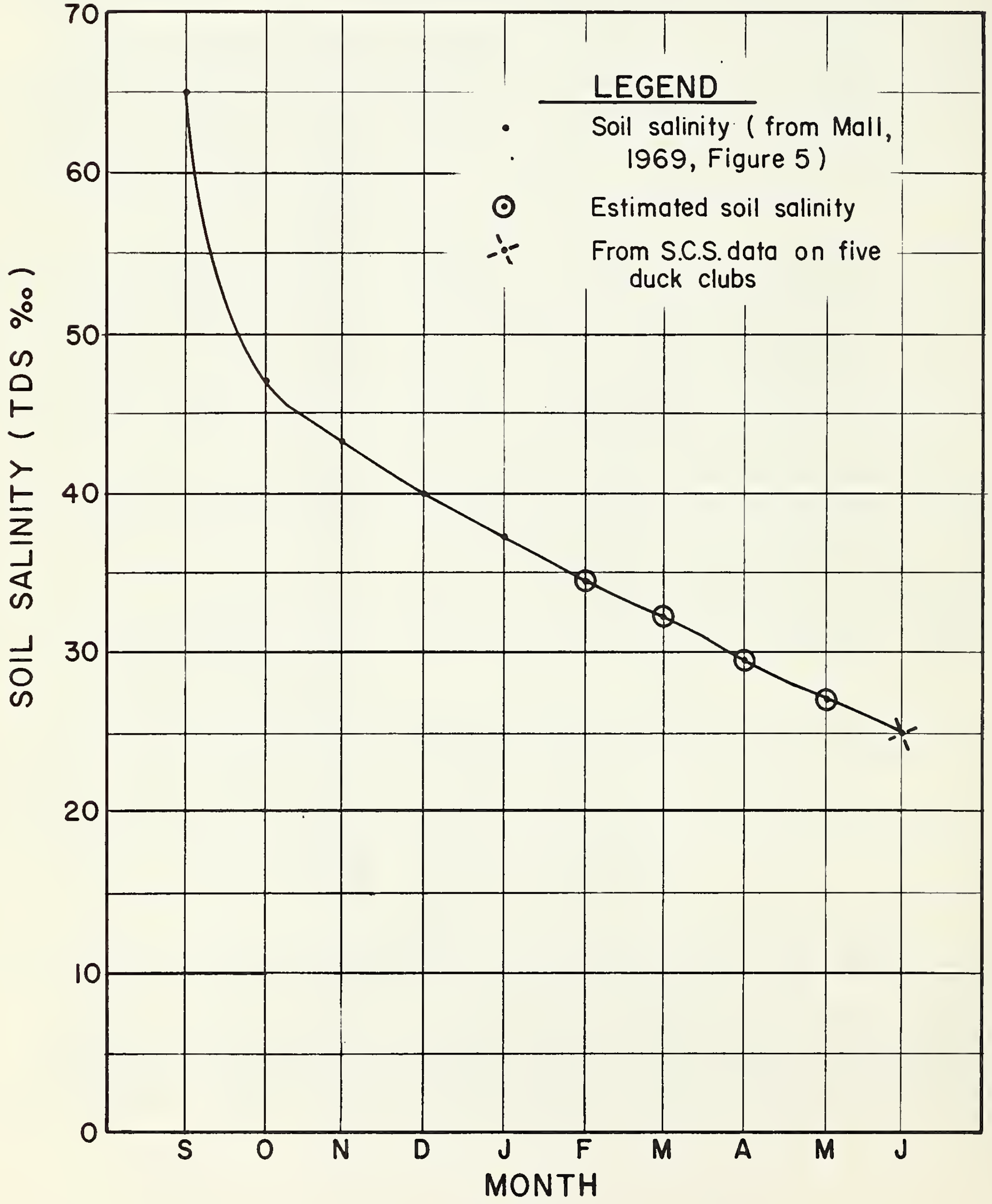
GENERALIZED OPERATIONS SCHEDULE FOR SEASONALLY FLOODED PONDS USING PRESENT WATER QUALITY WITH EXISTING FACILITIES AND MANAGEMENT

MONTH	SLOUGH SALINITY IN mmhos E.C.1/2/	POND WATER SALINITY mmhos E.C.3/	POND SOIL SALINITY4/	RECOMMENDED MANAGEMENT ACTIVITY AND OBJECTIVES
September	5.0 (3.2)	5.5 (3.7)	64.5 (43.0)	Fill ditches, interior sloughs, and soil profile.
October	3.9 (2.5)	22.0 (14.0)	46.5 (31.0)	Fill ponds and then set tide gates to circulate water to reduce salinity and replace water lost to evaporation and transpiration.
November	5.6 (3.6)	20.3 (13.0)	33.0 (22.0)	Continue to circulate water through ponds to improve water quality and reduce salt load.
December	4.4 (2.8)	17.0 (11.0)	30.0 (20.0)	Circulate water to improve water quality and reduce salt in ponds.
January 1	1.8 (1.2)	10.5 (7.0)	27.0 (18.0)	Continue circulating water until the end of the hunting season.
January 15 thru February to March 15	1.6 (1.1)	9.0 (6.0)	25.0 (16.8)	Drain and refill ponds at least twice at 3/4 shooting level.
March 15 to March 31	1.5 (1.0)	12.0 (8.0)	22.0 (14.7)	Hold pond level at 3/4 shooting level. Set tide gates to circulate water thru ponds to prevent salt accumulation.
April	1.8 (1.1)	13.5 (9.0)	20.0 (13.4)	Circulate water to replace evaporation and consumptive use and maintain water quality.
May	4.8 (3.1)	16.5 (11.0)	17.0 (11.4)	Continue to circulate water to replace evaporation and consumptive use.
June 1	-	-	14.7 (9.8)	Set tide gates to drain ponds.

1/ Seven year average salinity from Table 23.
2/ Approximate total dissolved solids in parts per thousand in parenthesis.
3/ Pond water salinities based on data developed by Mall (1969 - Table 5).
4/ Pond soil salinities based on data developed by Mall (1969 - Table 5) for October to January and SCS data for June (See Figure 10).

Figure 10

ESTIMATED POND SOIL SALINITY UNDER PRESENT WATER QUALITY CONDITIONS IN SUISUN MARSH



(1) obtain a desirable water quality in the ponds in May, and (2) determine the quantity of circulation water needed to accomplish this.

The calculated quantities of water needed to carry out the various operations outlined in Table 24 are given in Table 25. Quantities needed for each item requiring water are given by month, with subtotals for the fall hunting season and for the post-hunting season period (January 15 to June 1). The following items form the basis for the figures in Table 25:

1. Area in interior sloughs - 1,200 acres with a volume of 7,200 acre-feet at shooting level and 6,800 acre-feet at 3/4 shooting level.
2. Area in ditches - 3,000 acres, with a volume of 9,000 acre-feet when full and 8,250 acre-feet at the 3/4 level.
3. Soil profile area to be saturated - 37,100 acres (including area under slough and ditches containing 44,500 acre-feet of water.)
4. Area in ponds - 32,900 acres, containing 41,100 acre-feet of water at shooting level and 30,800 acre-feet at the 3/4 level.
5. Total area under water - 37,100 acres, containing 102,500 acre-feet when flooded to shooting level and 90,350 acre-feet at the 3/4 level.

The figures outlined in Table 25 are presented graphically in Figure 11 by time of year and quantity of water. Each point on a line represents a cumulative quantity of water used at that point for the factors shown below the line.

Although the soil and water quality study produced a limited amount of data, it was felt that some interesting conclusions could be drawn regarding current water use patterns. These patterns indicate that the clubs apparently could not take advantage of better quality waters in sloughs. This was evident in that, while good water was available in sloughs, the quality on the clubs often remained poor. In some cases as the slough quality continued to become better at a rapid rate, the rate of improvement of club water quality decreased until almost no improvement occurred. Figure 12 shows the average slough and club water qualities observed. It is recognized that, while the period of time represented by these samples is too short to draw substantive conclusions, these data are an indicator of what is happening in the relationship between the tidal sloughs and the ponds.

An obvious conclusion is that there is a substantial increase in salinity of water in the ponds as compared to salinity of water outside the levees. As the quality of slough water becomes better, the difference between it and the quality of water in ponds becomes greater. In general, there is a twofold increase in salinity from slough to pond water, as a one year average; however,

TABLE 25

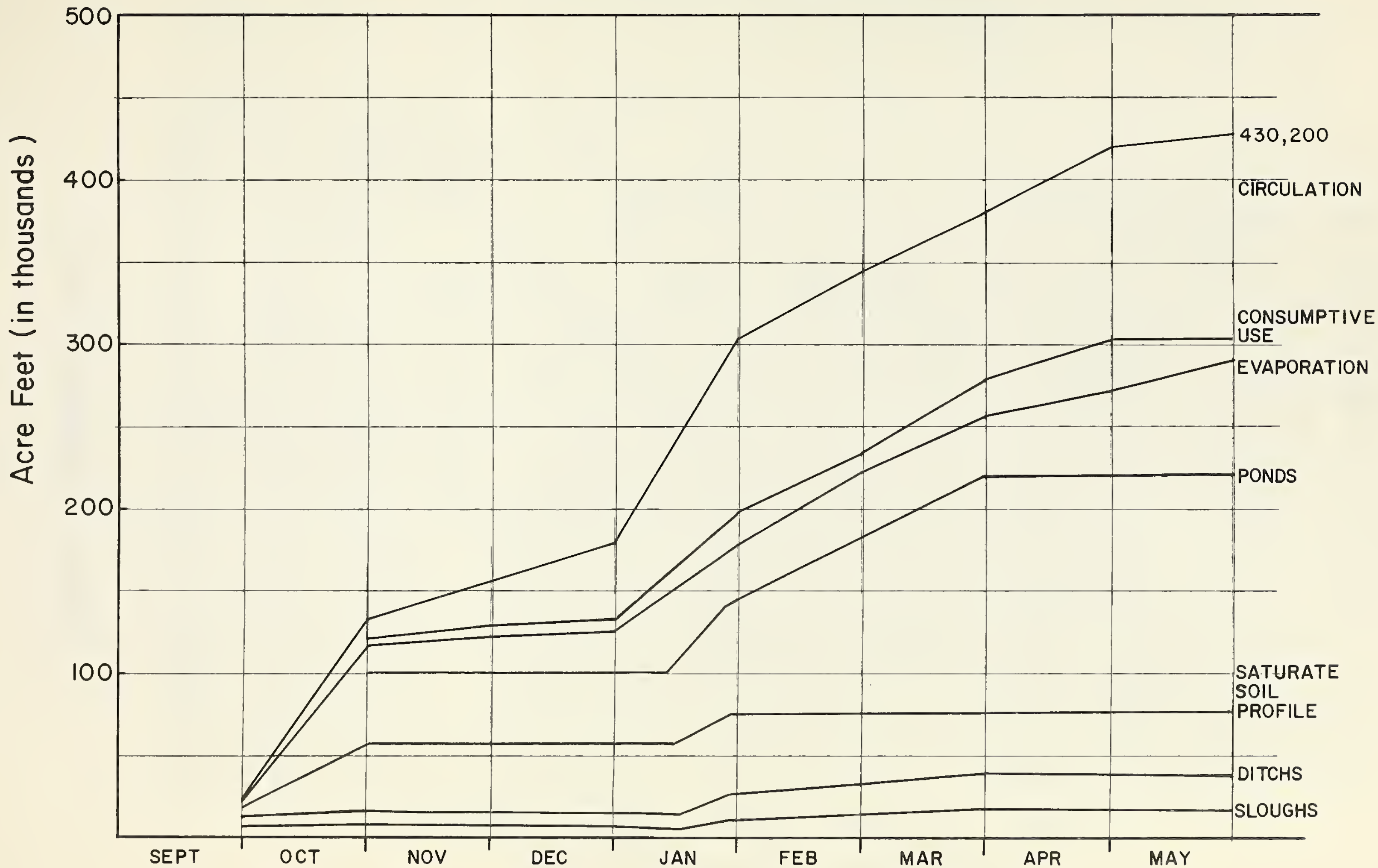
WATER REQUIREMENTS FOR ALL SEASONALLY FLOODED PONDS

QUANTITY OF WATER NEEDED IN ACRE FEET

Time Period	Interior Sloughs	Ditches	Soil Profile	Ponds	Evaporation	Consumptive Use	Water Circulation	Total by Time Period	Acre Feet Supplied By Rainfall and Runoff by Month	Remaining Acre Foot Requirement	Total Applied Water
SEPTEMBER	5,400	6,000	5,000	--	2,600	--	--	19,000	1,200	17,800	
OCTOBER	1,800	3,000	39,000	41,100	11,600	6,000	31,600	134,100	5,300	128,800	
NOVEMBER	--	--	--	--	7,500	3,000	29.000	39,500	15,500	24,000	
DECEMBER	--	--	--	--	3,700	700	26,800	31,200	15,800	15,400	
JANUARY 1 TO 15	--	--	--	--	1,900	1,100	49,900	52,900	11,950	40,950	
SUB-TOTAL (SEPTEMBER TO JANUARY 15)	7,200	9,000	44,000	41,100	27,300	10,800	137,300	276,700	49,750	--	226,950
JANUARY 15 TO 31	5,400	6,000	5,000	30,800	1,700	1,600	6,800	57,300	11,950	45,350	
FEBRUARY (Fill and Drain)	3,000	3,000	--	30,900	3,400	2,200	5,900	48,400	17,600	30,800	
MARCH (Fill and Drain)	3,000	3,000	--	30,800	3,500	2,200	5,600	48,100	5,100	43,000	
APRIL	--	--	--	--	13,100	12,000	30,800	55,900	1,400	54,500	
MAY	--	--	--	--	17,300	13,200	--	30,500	900	29,600	
SUB-TOTAL (JANUARY 15 TO MAY 31)	11,400	12,000	5,000	92,500	39,000	31,200	49,100	240,200	36,950	--	203,250
TOTAL ANNUAL REQUIREMENT	18,600	21,000	49,000	133,600	66,300	42,000	186,400	516,400	86,700	--	430,200

Figure 11

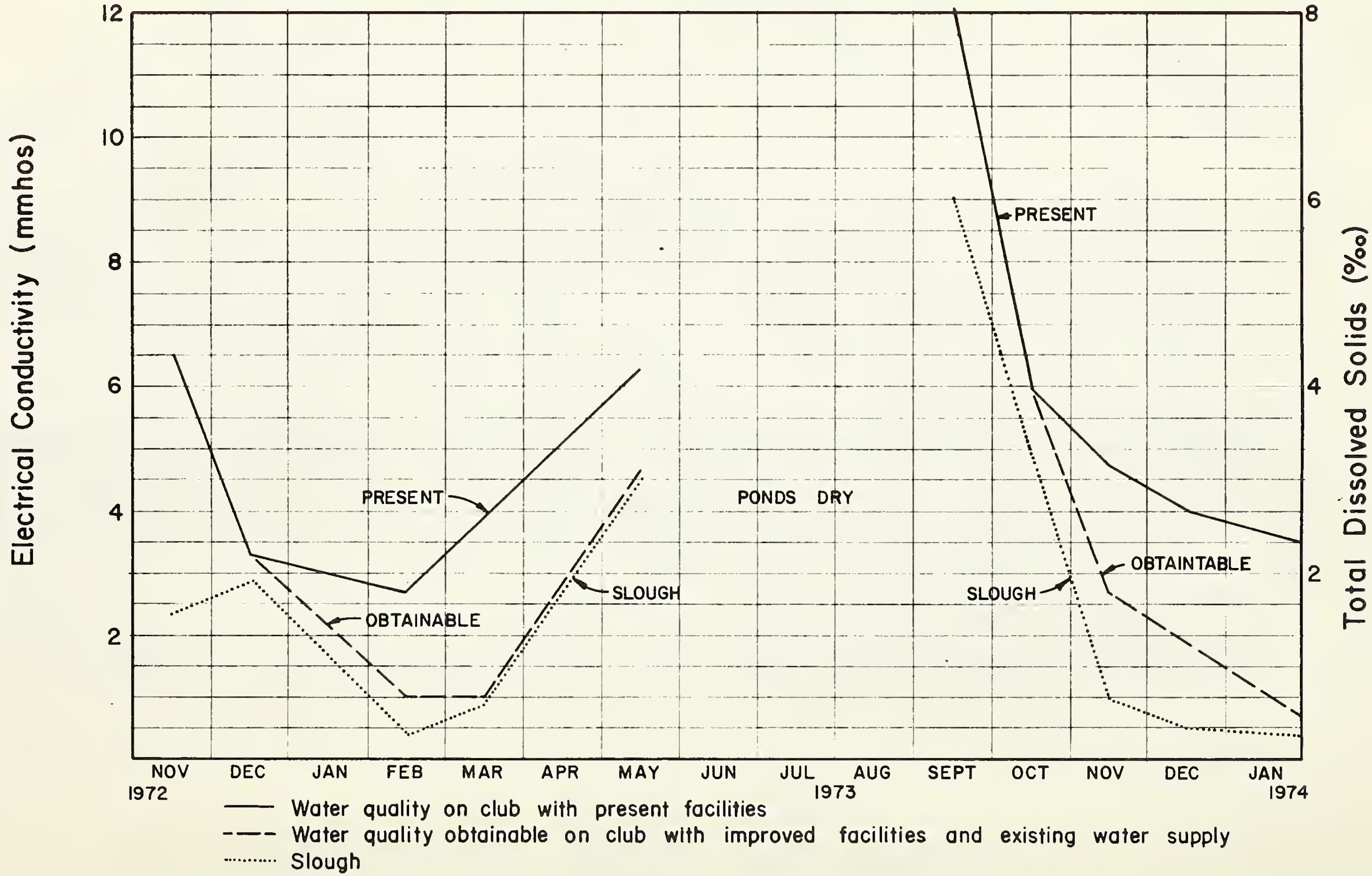
CUMULATIVE WATER REQUIREMENTS FOR SUISUN MARSH



Based on information in Tables 25 and 26 with improved water management facilities.

Figure 12

RELATIONSHIP BETWEEN SLOUGH AND CLUB WATER QUALITY



with adequate facilities and proper management clubs may be able to reduce the variation between pond and slough water quality.

PROPOSED WATER DISTRIBUTION SYSTEM

In addition to the attempt to relate present water quality in sloughs to water quality in clubs an appraisal was made of projected water salinities for the Suisun Marsh area under conditions of full water development as projected for the year 2020 (California Department of Water Resources, unpublished data). A 47 year monthly average for total dissolved solids was determined for each of four stations for which projections were available (Benicia, Port Chicago - opposite Ryer Island, Chipps Island and Collinsville). These monthly averages were plotted (Figure 13). From the graph of water quality and assuming the average salinity relationship between the tidal water and ponds that exists under present conditions (pond salinity twice that of slough water), the downstream limit of usable quality water would be around Collinsville. The water at Chipps Island would be usable but would be of marginal quality during April and May which is the critical time of year for seed production (Mall, 1969). The quality projected for Port Chicago would be too salty to permit seed production of alkali bulrush or the other desirable plants.

The predicted water quality for Port Chicago is used in Table 26 for the tidal slough in the Marsh to determine the salinity that could be expected in the ponds. The maximum and minimum average salinities were given in electrical conductivity and total dissolved solids. The maximum pond salinities indicated would be at or near the upper tolerance level of most marsh plants. Alkali bulrush and other desirable food plants would probably survive such salinities for a season or two but little or no seed would be produced. In wet years, with minimum salinity conditions, the surviving plants would do well. However, the average conditions would likely reflect the productivity of the Marsh and so they were used.

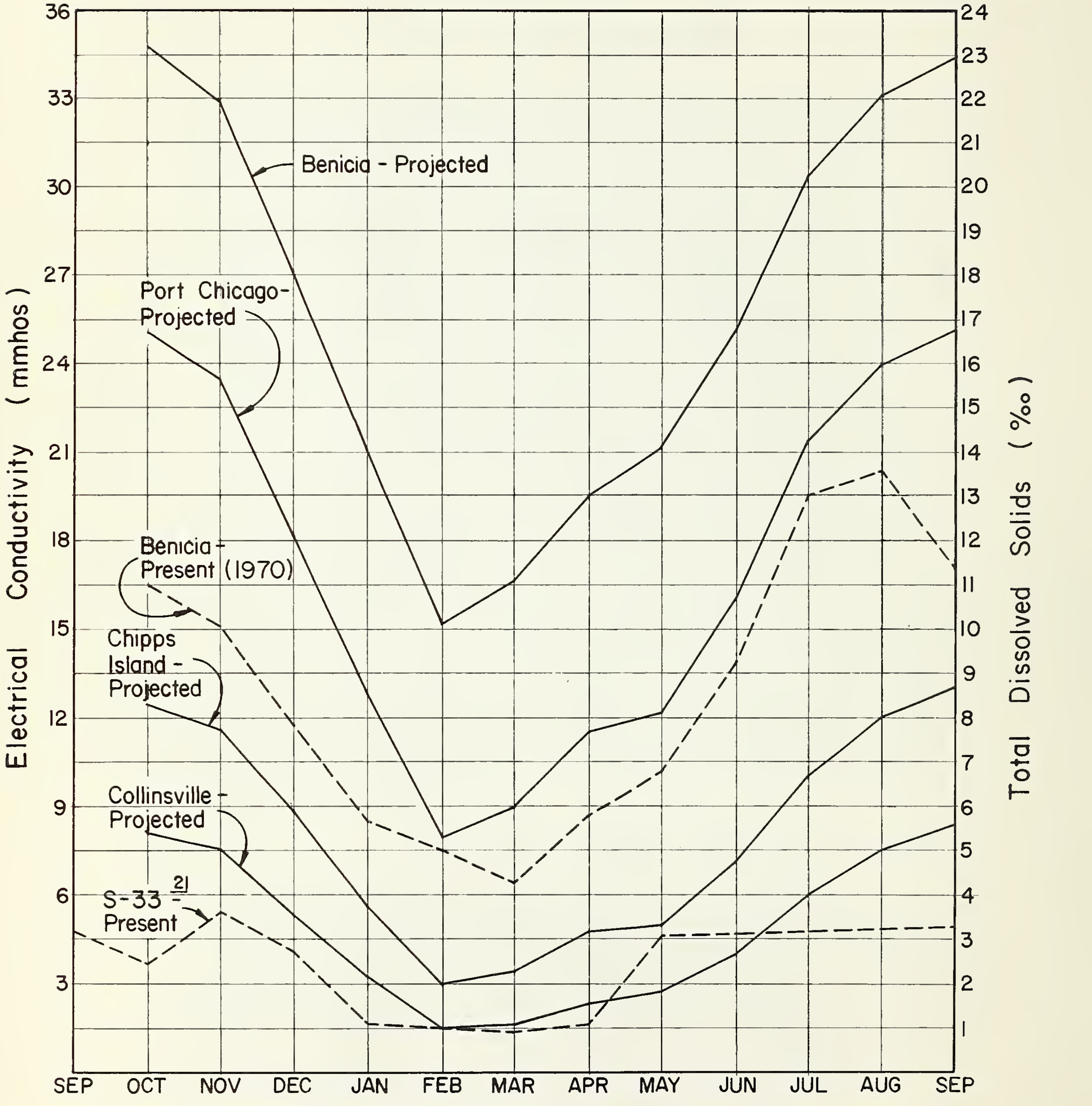
FACILITIES NEEDED FOR A NEW SOURCE OF WATER

Once the quantity of water needed was established for the Marsh (Table 25 and Figure 11) it became possible to determine the period of peak water demand and the size of the facilities needed to distribute a new source of water to the duck clubs. It was also necessary to determine a logical system for accomplishing the distribution of this water. To do so the following assumptions were made:

1. The main source of water will be from the north, in quan-

Figure 13

SALINITIES FOR THE SUISUN ESTUARY [1]



[1] From data furnished by the California Department of Water Resources and The U.S. Bureau of Reclamation, 1974.

[2] Cordelia slough at Cygnus station, Survey Group I.

*Projected data is average of yearly projections to A.D. 2020 with Peripheral Canal.

TABLE 26

MONTHLY SUMMARY OF PREDICTED WATER QUALITY OF TIDAL SLOUGHS FOR THE YEAR 2020[1/] AND THE RESULTING WATER QUALITY IN PONDS

Month	Salinity of Tidal Water [2/]						Salinity of Water in Ponds					
	Average		Maximum		Minimum		Average		Maximum		Minimum	
	EC(mmhos)	TDS(0/00)	EC(mmhos)	TDS(0/00)	EC(mmhos)	TDS(0/00)	EC(mmhos)	TDS(0/00)	EC(mmhos)	TDS(0/00)	EC(mmhos)	TDS(0/00)
October	26.3	16.8	34.2	21.9	8.5	5.5	39.4	25.2	51.3	32.8	14.9	9.5
November	24.6	15.7	33.1	21.2	5.7	3.7	36.9	23.6	49.7	31.8	11.4	7.3
December	18.7	12.0	31.3	20.0	0.6	0.4	28.1	18.0	46.9	30.0	1.2	0.8
January	13.2	8.4	29.8	19.1	0.2	0.1	19.7	12.6	44.8	28.7	0.3	0.2
February	8.0	5.1	28.9	18.5	0.2	0.1	14.0	9.0	43.4	27.8	0.3	0.2
March	9.0	5.8	25.8	16.5	0.2	0.1	13.5	10.1	38.7	24.9	0.3	0.2
April	11.7	7.5	27.2	17.4	0.2	0.1	20.4	13.1	40.8	26.1	0.3	0.2
May	12.4	7.9	29.8	19.1	0.9	0.6	20.5	13.1	44.7	28.6	1.9	1.2
June	16.6	10.6	29.6	18.9	2.0	1.3	25.0	16.0	44.3	28.4	4.1	2.6
July	22.3	14.3	31.2	20.0	9.6	6.2	33.5	21.4	46.8	29.9	14.5	10.8
August	25.1	16.1	31.7	20.3	18.0	11.5	37.7	24.1	47.5	30.4	27.0	17.3
September	26.4	16.9	31.9	20.4	22.2	14.2	39.6	25.4	47.9	30.6	33.3	21.3

1/ Based on the average of projections for a 47 year period with the peripheral canal in operation. Taken from data supplied by George Deathridge, Department of Water Resources, Sacramento, California.

2/ Using projected conditions for the estuary at Port Chicago.

tities sufficient to meet requirements of the recommended management schedule.

2. Water will go into a system within the Marsh boundaries and will be transported to all parts of the Marsh that can be reached within the topographic or other existing physical constraints.

3. A portion of the Marsh will probably receive water from the present source. This would be the area in the southeast corner (Group VI) which is supplied directly from the Sacramento River. It would include the islands that cannot be reached effectively with water from the north: Chipps Island, Ryer Island and other small islands in Suisun Bay.

Natural sub-divisions of the Marsh were used to determine the general scheme of distribution. Major sloughs were by-passed because of the large volume of water required to fill them, the cost of separating them from Suisun Bay, and other complications. The acreage of each sub-area, and the quantity of water needed to serve them was determined.

Sizes of new canals required to carry the water were then determined and those minor sloughs which could be used to convey water throughout the Marsh were identified. Work needed to close the sloughs at their confluence with major sloughs or bays was estimated.

The individual club inlet and outlet needs were appraised. Where existing facilities would serve, it was so noted. Where new inlets and outlets were required, the size necessary to accomodate the flow was determined and a cost estimated (Plate 15, Pocket inside Cover). It was found that 40 clubs covering 16,100 acres needed revised or additional inlet facilities. A similar number of clubs needed additional outlet facilities. Computations indicated that about 3.1 million cubic yards of earth transport would be needed to construct the conveyance system. This would be in addition to 1.4 million cubic yards of levee work identified in the section on physical facilities.

It was felt that an even better job of protection from tidal intrusion than the average condition outlined in the section on physical facilities would be needed to justify the large expenditure of money for the conveyance system. Consequently, the levee cross-sections were increased so that all levees less than 7 feet high and with top widths less than 25 feet were brought up to this size. The earth movement required was 3.6 million cubic yards. Side slopes remained 2:1 and 1 1/2:1.

In addition to these features, some 25 sloughs would have to be blocked off at costs varying from $3,000 to $15,000. An average cost of $8,000 was used. Spreader ditches referred to earlier would still require 608,000 cubic yards of earth moving. One major slough crossing located under Montezuma Slough would be needed. The cost of constructing an inverted syphon type crossing having a acapacity of 1,100 cubic feet per second would be about $800,000.

Next a determination was made of quantities and costs for construction of ditches and canals. Approximately 2,778,000 cubic yards of earth would be moved in the construction of the canals. This quantity was increased to 3,100,000 cubic yards to take into account the additional levee height required for proper functioning of canals with inverts below sea level. A price of $2.00 per yard was established for this item resulting in a total cost of $6,200,000.

The facilities needed and costs to install the distribution system plus improvements required on the clubs are listed in Table 27.

A total cost of up to 26.0 million dollars might be necessary depending on ground conditions encountered and unanticipated cost factors revealed by a detailed survey.

The distribution system had to be designed to handle the peak flow required to meet the maximum demand for water in the Marsh. October was found to be the month with the highest demand figure (Table 26) with a need to deliver 109,840 acre-feet of water. This required a flow of 2,900 cubic feet per second, which was used to size the initial section of the distribution canal. The various branches were sized according to the area serviced.

The use of open, unlined ditches and smaller sloughs were to be used as distributaries wherever possible. Using these minor sloughs for distribution made it necessary to block off their entrances into the major sloughs to check tidal effects.

Since the water would be delivered, in many cases, at the opposite end of a club from where the tidal water entered, it now became necessary to re-establish inlets and outlets on the clubs and reorganize the circulation system through the ponds. Therefore, the spreader ditches became more important and a need to regrade many ditches was anticipated. The associated cost of this was included in Table 21.

Bringing water to the Marsh from an outside source, i.e. an over land conveyance of water other than tide water, is feasible. The distribution of such water could be quite expensive and will present both engineering and construction problems, neither of which are considered unsurmountable. Should a source of water be developed that is of better quality than that currently being used, a lesser amount of water would be required to produce the same quantity and quality of habitat as is currently being produced. The reduced demand for circulation water needed for salinity control would account for the lower water requirement.

The discussion in the foregoing section is very preliminary in nature and is only intended to provide a concept and a rough

TABLE 27

ESTIMATE OF FACILITIES NEEDED AND COST ESTIMATES
FOR THE DEVELOPMENT OF A SUPPLEMENTAL
WATER DISTRIBUTION SYSTEM IN SUISUN MARSH

ITEM	QUANTITY	COST RATE	TOTAL COST**
Levees (outside)	3.6 m.c.y.*	$2.00/c.y.	7.2
Levees (inside)	.9 m.c.y.	$1.00/c.y.	0.9
Distribution System	3.1 m.c.y.	$2.00/c.y.	6.2
Inlets	161 pipe & 322 gates	$4,000 ea. pipe	0.7
Outlets	75 pipe & 150 gates	$4,000 ea. pipe	0.3
Spreader Ditch	0.65 m.c.y.	$2.00/c.y.	1.3
Slough Closure	25 ea.	$8,000 ea.	0.2
Slough Crossing	1 ea.	$0.8 million	0.8
			17.6
Plus 15% escalation and contingencies			5.3
			22.9

* Million cubic yards ** Millions of dollars

preliminary estimate of quantities and costs. To refine the concept and firm up the cost estimates would take much more time and additional studies. Major considerations would have to include determinations of areas needing improved quality water and feasable sources of water.

PROJECTED CONDITIONS

WITH PRESENT WATER QUALITY

If the present water quality could be maintained, the value of Suisun Marsh as a waterfowl area could be preserved and enhanced. During the past decade, additional fresh water has been diverted from the Delta system. However, vegetation studies cited earlier indicate that the acreage of alkali bulrush, fat hen and brass buttons - the three most important waterfowl food plants - has increased during this period. Water management on many clubs has been improved during the past ten years, due to the Suisun Resource Conservation District Program and technical assistance from DFG and SCS. This probably accounts for the increase in these plants. However, the margin of safety in regards to soil salinity is not great. Rollins' studies (Rollins, 1973) indicated that the water management on some clubs was insufficient to maintain the desired soil moisture salinity of 9 to 14 0/00 (14.0 to 21.0 mmhos E.C.) in May that is optimum for alkali bulrush seed production. However, if all of the clubs had adequate facilities - tide gates, spreader ditches and drains - described in the previous section, they could maintain the proper salt balance most of the time (Table 24). With careful management, it should be possible to reduce the acreage of pickleweed and convert some of it to the more productive waterfowl food plants such as alkali bulrush, reduce the spread of hardstem bulrush, and keep cattail under control.

WITH IMPROVED WATER QUALITY

If an alternate source of high-quality water with a salinity of less than 2 0/00 (3.0 mmhos E.C.) were available and a distribution system developed for the Suisun Marsh, it would be possible to gradually reduce the soil salinity in the root zone to where the less salt-tolerant waterfowl food plants could be grown. High yielding crops such as barley, corn, milo and Japanese millet could be planted annually. Also, self-perpetuating annuals such as barnyardgrass (watergrass), nodding smartweed, knotgrass, wiregrass and the like could be used, as well as arrowheads, (*Sagittaria*), burreeds (*Sparganium*), spikerush and submersed aquatics such as horned pondweed (*Zannichellia pallustris*). This would increase the potential value of the Marsh for waterfowl because of the greater variety of food plants that could be grown and increased production per acre that would be possible. However, it would also increase the problem of cattail and tule control. These plants and other competing perennials such as river bulrush (*Scirpus fluviatilis*), Olney bulrush, common reed (*Phragmites communis*), Baltic rush, etc., thrive under fresh water conditions. As indicated earlier, they produce very little food for ducks and tend to crowd out the more valuable seed producing plants. Without intensive management, the shallow ponds of the Marsh would develop into solid jungles of heavy vegetation similar to that found on the small unleveed islands in the Delta - described by Griffith (1963, Appendix C).

Under fresh water conditions, marsh management practices similar to those used on waterfowl refuges in the Central Valley - as described by Ermakoff (1968) - would have to be used. The ponds would have to be drained early in the spring most of the time to allow the soil to dry out to where farming equipment could be used to prepare a seed bed for planting crops and to control cattail and tule growth. Most crops, such as corn would have to be sprinkler irrigated during the summer, or land smoothing and grading would have to be accomplished to facilitate irrigation by other methods. However, the following year after the planting of a crop, self-perpetuating annuals could be allowed to volunteer, producing an early crop of seed that would require less irrigation. This could be repeated another year or two until undesirable plants dominated the ponds. Then the ponds would have to be drained and fallowed one season to kill the weeds, returning the pond to a "bare-ground" stage again, which would eliminate habitat. The following spring a planted crop could be used and the cycle started over again. An alternative in deeper ponds would be to flood the pond deeply enough for one season or more to drown out the competition. Sago pondweed and horned pondweed would have to be used as the duck food plants during the flooded season.

Mosquito abatement problems would be severe where summer irrigation was necessary. Precise water control is necessary to avoid mosquito production and few, if any, of the ponds are leveled to the degree necessary to accomplish this. Converting to a fresh water marsh would solve the problem of excess salinity and increase the potential value for waterfowl food production, but would also create other serious management problems.

WITH DEGRADED WATER QUALITY

If water quality in the Suisun Marsh is allowed to degrade as more fresh water is diverted for other uses, salinity could seriously affect the value of the Marsh for waterfowl. The increase in salinity would likely be gradual. For a number of years the duck clubs could maintain desirable habitat by improving their water management and facilities to handle water to optimize circulation. As salinity of tidal sloughs increased, the length of soil submergence on the clubs would have to be increased to prevent the soil salinity in the root zone from exceeding the limit that desirable plants could tolerate. Eventually the ponds would have to remain flooded year around. Otherwise, soil salinity during the dry period in the summer would exceed the tolerance of the most desirable marsh plants and only pickleweed and saltgrass would survive.

Data collected on the salinity of tidal water indicated a considerable variation existed from one end of the Marsh to the other, depending on the mixture of fresh water with sea water.

As the salinity increases in the estuary in future years, this variation in tidal slough salinity should continue to exist and possibly intensify. Therefore, it would be difficult to describe a single management plan that would fit all clubs. However, the basic scheme for any plan would be to maintain a soil moisture salinity in the root zone that desirable plants could tolerate. For conditions projected for the year 2020, it was desirable to separate or stratify the Marsh into three groups according to the salinity gradient of tidal water. The basis for this was the preliminary data on water quality monitoring summarized for the Suisun Marsh Research and Testing Program (Bureau of Reclamation, 1972) and the water quality data presented in Figure 3 compared with salinities of the estuary at Benicia, Port Chicago, Chipps Island and Collinsville. The clubs in Group IV (Plate 2) nearest Benicia would be using water with the highest salt content - similar in quality to that projected for Port Chicago (Figure 13). At the other extreme, the clubs in Group VI, nearest the Delta, would be using water with a salinity similar to that projected for Chipps Island. The clubs in Groups I, II, III and V would be using water with a salinity in between these extremes or similar in quality to that recorded for Benicia in recent years (Figure 13).

As mentioned before, water quality predicted for Chipps Island would be only little more saline than the water quality that exists presently in the western part of the Marsh (Group IV clubs). It is possible that Group VI clubs, therefore, could continue to maintain good waterfowl habitat using the districts recommended marsh management plan if they optimized their water circulation facilities - tidegates, spreader ditches and drains. They would follow a water management schedule similar to that presented in Table 28.

It would appear that the ponds on clubs in Groups I, II, III and V, with tidal water of intermediate salinity, might be operated as seasonally flooded ponds as they have been in the past if water management was optimized. Table 29 gives predicted salinities and necessary operation schedule. This might produce marginal habitat in view of Rollins' observations (Rollins, 1973); however, the same marsh plants occur in the tidal marsh at Martinez, California, across the Carquinez Straits from Benicia at present. If the salinity in the root zone cannot be stabilized at a tolerable level, 9 to 14 0/00 or (13.5 to 21.0 mmhos E.C. - Mall, 1969) each spring in May then the ponds would have to be kept flooded through the summer. Theoretically, it should be possible to optimize circulation and keep the salinity in the ponds below 14 0/00 (21.0 mmhos E.C.) during May (Table 30). With the existing water control facilities most clubs probably could not maintain a salinity level of less than 18 0/00 (27 mmhos E.C.) and if the

TABLE 28

GENERALIZED OPERATIONS SCHEDULE FOR SEASONALLY FLOODED PONDS AND ANTICIPATED EFFECTS RESULTING FROM THE USE OF TIDAL WATER EQUAL TO THAT PROJECTED FOR YEAR 2020 AT CHIPPS ISLAND

MONTH	TIDEWATER SALINITY IN mmhos E.C.1/	CLUB WATER SALINITY mmhos E.C.1/	OPTIMUM POND SALINITY OBTAINABLE mmhos E.C.1/	WATER MANAGEMENT ACTIVITY AND OBJECTIVES
September	13.0 (8.7)	30.0 (20.0)	19.6 (13.1)	Fill ditches, interior sloughs, and soil profile.
October	12.6 (8.4)	25.2 (16.8)	18.9 (12.6)	Fill ponds and set tidegates to circulate. Replace more saline water with less saline water as the season progresses.
November	11.7 (7.8)	23.4 (15.6)	17.5 (11.7)	
December	8.7 (5.8)	17.4 (11.6)	13.0 (8.7)	
January	5.5 (3.7)	11.1 (7.4)	8.4 (5.6)	Drain ponds and refill to 3/4 shooting level.
February	3.0 (2.0)	6.0 (4.0)	4.5 (3.0)	Drain and fill to 3/4 shooting level.
March	3.6 (2.4)	7.2 (4.8)	5.4 (3.6)	Set tide gates to circulate so as to replace water lost to evaporation and consumptive use, preventing the accumulation of salt.
April	4.8 (3.2)	9.6 (6.4)	7.2 (4.8)	
May	5.2 (3.5)	10.5 (7.0)	7.8 (5.2)	
June	7.2 (4.8)	14.4 (9.6)	10.8 (7.2)	Drain ponds.

1/ Approximate parts per thousand - TDS in parenthesis

TABLE 29

GENERALIZED OPERATION SCHEDULE FOR PONDS USING PREDICTED WATER QUALITY (YEAR 2020) WITH OPTIMUM FACILITIES AND MANAGEMENT

MONTH	TIDAL SLOUGH SALINITY 1/ mmhos E.C. 2/	PROBABLE POND SALINITY WITH ADEQUATE WATER CONTROLS AND MANAGEMENT mmhos E.C.	POTENTIAL POND SALINITY WITH OPTIMUM CIRCULATION mmhos E.C.	ACTIVITY AND OBJECTIVE
September	18.0 (12.0)	36.0 (24.0)	27.0 (18.0)	Fill ditches, interior sloughs, and saturate soil profile.
October	16.5 (11.0)	33.0 (22.0)	25.5 (17.0)	Fill ponds to shooting level, set tidegates to circulate water to replace water lost to evaporation and consumptive use.
November	15.1 (10.1)	30.3 (20.2)	22.5 (15.0)	Circulate water to replace evaporation and consumptive use.
December	11.7 (7.8)	23.1 (15.4)	16.5 (11.0)	Circulate to exchange poorer quality water and replace evaporation and consumptive use losses.
January	8.4 (5.6)	13.1 (11.2)	16.5 (8.0)	Circulate to exchange poorer quality water and replace evaporation and consumptive use losses.
February	7.5 (5.0)	15.0 (10.0)	11.2 (7.5)	Drain and refill to 3/4 shooting level.
March	6.6 (4.4)	13.2 (8.8)	9.9 (6.6)	Drain and refill to 3/4 shooting level and also replace evaporation and consumptive use losses.
April	8.7 (5.8)	17.4 (11.6)	12.0 (8.7)	Circulate only to maintain pond level to 3/4 shooting level and replace evaporation and consumptive use losses.
May	10.0 (6.7)	20.1 (13.4)	15.0 (10.0)	Circulate only enough to maintain 3/4 shooting level.
June	13.4 (9.3)	27.9 (18.6)	21.0 (14.0)	Continue to circulate to maintain pond level at 3/4 shooting level until alkali bulrush seed is mature, then drain ponds.

1/ Projected salinity based on 47 year average (1973 to 2020), intermediate of Port Chicago and Chipps Island salinity (comparable to present salinity at Benicia) - Figure 13.

2/ Approximate parts per thousand, TDS in parenthesis.

TABLE 30

GENERALIZED OPERATIONS SCHEDULE FOR PONDS USING PROJECTED, YEAR 2020, WATER QUALITY FOR PORT CHICAGO

	TIDEWATER (SOURCE) SALINITY IN mmhos E.E. 1/	PROBABLE CLUB WATER SALINITY mmhos E.C. 1/	OPTIMUM POND SALINITY OBTAINABLE mmhos E.C. 1/	WATER MANAGEMENT ACTIVITY AND OBJECTIVES
September	26.4 (16.9)	52.8 (33.8)	39.6 (25.4)	Ponds permanently flooded.
October	26.3 (16.8)	52.6 (33.6)	39.4 (25.2)	Bring water to shooting level during the season.
November	24.6 (15.7)	49.2 (30.4)	36.9 (23.6)	Circulate to replace water lost to evaporation and transpiration, as well as saline water with less saline water.
December	18.7 (12.0)	37.4 (24.9)	28.1 (18.0)	
January	13.2 (8.4)	26.4 (16.9)	19.7 (14.7)	
February	8.0 (5.1)	16.0 (10.7)	14.0 (9.0)	At the end of hunting season drain ponds completely and refill to 3/4 shooting level. Drain ponds and refill to 3/4 shooting level while tidal water is the freshest. Maintain water at 3/4 shooting level by adding water to replace that lost.
March	9.0 (5.8)	18.0 (12.0)	13.5 (10.1)	
April	11.7 (7.5)	23.4 (15.6)	20.4 (13.1)	
May	12.4 (7.9)	24.9 (16.6)	20.5 (13.1)	
June	16.6 (10.6)	33.2 (22.1)	25.0 (16.0)	Circulate water through ponds to maintain the lowest salinity possible the rest of the season.
July	22.3 (14.3)	44.6 (29.6)	33.5 (21.4)	
August	25.1 (16.1)	50.2 (33.5)	37.7 (24.1)	

1/ Approximate parts per thousand, TDS in parenthesis ponds were drained by June 1, as is usual for seasonally flooded ponds, the summer soil salinity would probably double - based on Mall's composited data (Mall, 1969). This would be beyond the tolerance of most of the desirable waterfowl food plants, and would be suitable only for plants such as pickleweed and saltgrass.

If these ponds are seasonally flooded, under ideal conditions, the vegetation would probably resemble that found on the Mulberry Land Club in 1973. Moderately salt-tolerant plants such as alkali bulrush, fat hen, and brass buttons would occur near the inlets where conditions were the least saline. Pickleweed and saltgrass would predominate over much of the remainder of the clubs. Where circulation and drainage were restricted or impeded bareground would occur. Cattail and less salt tolerant plants would not be abundant. In general, the number of plant species present would be reduced due to the brackish water condition.

If it were necessary to continually flood the ponds using tidal water to keep soil moisture salinity in the root zone within the tolerance of desirable waterfowl food plants, the vegetation pattern would change. The very shallow pond margins (zero to three inches) would be dominated by saltgrass and pickleweed. Slightly deeper water (2 to 24 inches) would be vegetated with alkali bulrush and some cattail and tule, while deeper water would support stands of widgeongrass. In either event the total productivity of the Marsh would be reduced.

Duck clubs in Group IV which would be using tidal water with a salinity comparable to that predicted for Port Chicago would probably have to manage the ponds on a continually flooded basis. Under these water quality conditions, it would be virtually impossible to achieve a soil moisture salinity in the ponds during April and May of less than 14 0/00 (21.0 mmhos E.C.) in most years. The salinity of the soil moisture in the root zone during the summer, if the ponds were drained in June, would probably be beyond the tolerance of the desirable waterfowl food plants. The salinity of tidal water available to the clubs would be considerably worse than that which has existed recently in the Carquinez Straits. With adequate water control facilities installed and properly managed it appears that pond water salinities attainable would be barely within the tolerance limits of the desirable waterfowl food plants (Table 30 and Figure 1). In years of extremely high precipitation the salinity would be within tolerable limits (Table 26) but this would happen too infrequently to maintain a productive marsh.

An operation schedule was designed for Group IV clubs using a water quality similar to that projected for Port Chicago, based on the average of 47 year projection for conditions in the estuary furnished by the Department of Water Resources and is presented in Table 30. It gives monthly tidewater salinity, probable pond water salinity, optimum pond water salinity obtainable and the water management activities schedule.

If the pond salinities indicated in Table 30 for Group IV clubs could be maintained, waterfowl food production would be minimal at best and the habitat provided would be of marginal quality. Widgeongrass, brass buttons, fat hen and alkali bulrush would occur, but pickleweed and saltgrass would predominate along with bare ground.

EVALUATION OF PROJECTED CONDITIONS

Mall (1969) compared waterfowl habitat in the Suisun Marsh with that of San Francisco Bay and concluded that there would be a serious reduction in carrying capacity of Suisun Marsh for ducks if water salinity increased as predicted. Other researchers have evaluated the waterfowl use on marshes of varying salinity and have concluded similarily that saline marshes do not sustain the levels of duck use that fresh and brackish marshes support.

The coastal marshes of Louisiana were studied by Chabreck (1971), and their value to fish and wildlife was assessed, based on the vegetation types produced. Mean water salinities for the four marsh types observed were: (1) saline, 18.1 0/00, (2) brackish, 8.2 0/00, (3) intermediate, 3.3 0/00, and (4) fresh, 1.0 0/00. The study indicated that the fresh, intermediate and brackish marshes were of high value to waterfowl, while saline marshes were of low value to most waterfowl. Fresh marshes had a high potential value but the overall quality of plants were rated lower than that of the intermediate and brackish types because less valuable plants for wildlife use tended to dominate the fresh marshes. Fewer plant species occurred in the brackish marsh but those present were choice waterfowl food plants.

The marshes of Delaware were studied by Chamberlain (1951). He found that an inverse relationship existed between waterfowl use per square mile and salinity. Marshes with a salinity range of zero to 9.9 0/00 averaged over 450 ducks per square mile while those with a salinity of 10.0 to 19.9 0/00 averaged about 100 ducks per square mile. Saline marshes having salinities above 20.0 0/00 averaged slightly more than 50 ducks per square mile. He also observed that as the salinity increased the number of plant species occurring in the marsh decreased.

Data furnished by Kay Johnson and Mark Barber, U.S. Fish and Wildlife Service, on duck use of four federal refuges in the Sacramento Valley indicate an intensity of use above 3,000 duck days per acre per year (two year average for 1972 and 1973). These data are not directly applicable to Suisun Marsh because the birds are concentrated during the hunting season on the refuges during the day but spread on to surrounding agricultural land at night to feed. Also, the refuges are managed intensively for waterfowl food production rather than for recreational hunting. However, this indicates the potential of intensively managed fresh-water marsh land.

It would appear that there will be increased costs involved in maintaining suitable waterfowl habitat in the Suisun Marsh in future years because of water development. Three options are:

(1) If water quality is degraded as projected, optimum conditions for alkali bulrush growth (9.0 0/00 water) may not be obtainable on private clubs unless existing water control facilities - tidegates, spreader ditches and drains - are improved considerably. The minimum amount would be the works of improvement outlined in Table 21. The costs involved would have to be balanced against the reduced quality of waterfowl habitat that would probably occur as a result.

(2) If an adequate amount of fresh water were brought into the whole Marsh a considerable amount of construction work would have to be accomplished as outlined in Table 27. The cost of this work and the cost of intensive marsh management that would be necessary annually plus the cost of water, would have to be balanced against the value of the improved habitat that would be produced.

(3) If supplemental fresh water were available for use in portions of the Marsh to help maintain present water quality in future years, the improvements listed in Table 21 would still be needed. In addition to this, additional construction would be necessary to distribute this water. These costs and the cost of the water would have to be taken into consideration in determining the cost benefit ratio of maintaining the present habitat quality. A major construction item under this option would be a means of supplying fresh water to the clubs in Group IV in the southwest corner of the Marsh - probably a canal down the west side of the Marsh from Cordelia. Supplemental fresh water released into Green Valley, Suisun, McCoy and Denverton Creeks might produce enough dilution to maintain satisfactory water quality for most of the rest of the Marsh. Again, Group VI clubs, near the Delta, might not require supplemental water.

SUMMARY

Suisun Marsh plays a very important part in providing habitat for waterfowl of the Pacific Flyway. It is also important to many other types of wildlife and fish. In addition, this 57,000 acres of marshland, along with the 27,000 acres of sloughs and bays is valuable as open space for a multitude of recreational activities. A major concern is that planned reductions in Delta outflow will seriously increase salinities and degrade water quality available for maintenance and management of the Marsh habitat. Significant vegetative change will occur that will substantially reduce the waterfowl carrying capacity of the Marsh if this happens. However, the development of alternative sources of water of sufficient quality for use in critical areas of the Marsh and the use of intensive marsh management practices can avert this damage. Present knowledge of marsh management based on ecological principles, recent research and experience indicates that soil salinities must be maintained at a level that desirable marsh plants can tolerate or the quality of the waterfowl habitat will deteriorate.

Generally, Suisun Marsh soils are highly organic and quite saline. Some of the soils are acid forming cat-clays. These factors and poor drainage severely limit the use of the Marsh for industrial, urban or agricultural development. The Soil Conservation Service recognizes wildlife habitat and recreation as the most compatible land use for these wetlands.

Field inventories were made on 109 private duck clubs in Suisun Marsh in 1973 to determine existing conditions. This information was used to project structural, management and water needs for development and maintenance of desirable waterfowl habitat. In addition, a hypothetical distribution system was developed to determine the cost of supplying fresh water to clubs in the Marsh.

The clubs in the Marsh were divided into six groups each having somewhat different conditions primarily related to the source of water. It was found that the clubs, where fresher water was available, in the southeast portion of the Marsh, had vegetative cover consisting primarily of alkali bulrush, cattail and tule. Cover on the clubs near Benicia was predominantly alkali bulrush and pickleweed. This was reflective of the more saline conditions. Other areas of the Marsh consisted of a more complex plant distribution pattern reflecting suitable water quality modified by water management or lack of proper water management. An evaluation of waterfowl habitat on managed portions of clubs inventoried indicated desirable plants provided 40 percent of the total cover.

Seven types of water management schedules were used by the

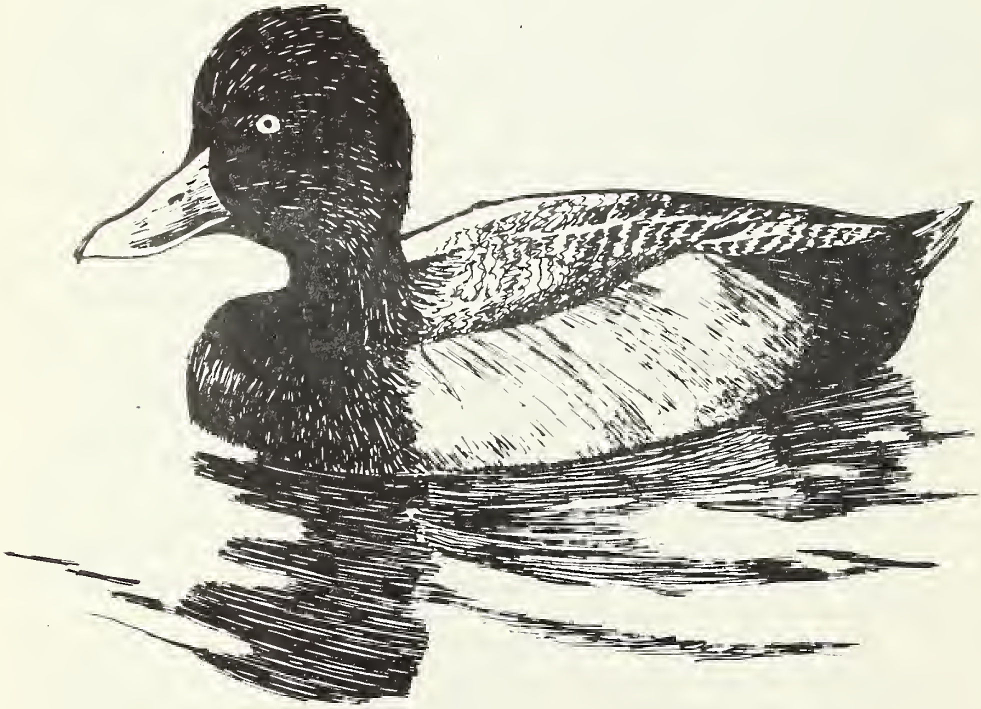
clubs that were inventoried. It was determined that water circulation and spring flushing cycles provided conditions best suited to production of alkali bulrush. Early drainage promoted growth of less desirable plant species such as pickleweed and saltgrass. Fat hen production was enhanced by water management which reduced soil salinity combined with soil disturbance and drainage later in the spring.

Samples of alkali bulrush seed indicated production was much greater under fresher water conditions and extended submergence, but this resulted in undesirable vegetative growth. The water management schedule recommended by the Suisun Resource Conservation District and developed by SCS and the California Department of Fish and Game and ratified by the Solano County Mosquito Abatement District resulted in the most desirable waterfowl habitat. It produced an adequate amount of food, primarily alkali bulrush seed and an acceptable amount of vegetative growth.

Based on the recommended water management schedule and its use by all duck clubs and the State of California Waterfowl Management Area, it was determined that approximately 430,200 acre-feet of water would be needed annually.

Appraisal of present water control facilities indicated what additional facilities would be needed to meet minimum requirements for proper water management whether tidal water with existing quality or poorer quality water were used. Improvements of levees is needed on an estimated 81 clubs to protect them from nine foot tides and on 77 clubs to allow individual water control between adjoining clubs. Levee improvements would cost an estimated 2.8 million dollars for exterior levees and $900,000 for interior levees. It was also determined that 105 clubs would need to improve existing spreader ditches or construct additional ditches costing an estimated 1.2 million dollars. Additional water control structures for flooding were needed on 74 clubs and for draining on 43 clubs in order for them to meet minimum requirements of the recommended water management schedule. This would cost about $558,000. Some clubs would need to install additional water control structures to allow water circulation through the club, even though in some instances the capacity to drain or flood is adequate. This would cost an additional $330,000. The total cost of bringing all clubs in the Marsh up to the minimum standard would be about $5.8 million.

Under projected water quality conditions, supplemental water may not be needed in all parts of Suisun Marsh. Additional water quality information is necessary to determine which areas will need a supplemental supply of fresh water. Realizing this limitation, a distribution system was designed to transport water to most areas of the Marsh. Besides the conveyance system, clubs would have to install additional structures to tap the supply and in some cases reverse direction of water flow through the club. Levee and spreader ditch improvements would also be required as previously mentioned. The total cost of providing this distribution system would be at least 17.6 million dollars. Alternative systems could be progressively developed as new sources of water become available for the Marsh. Ultimately, something less than the proposed system would probably be developed which could mean a proportional reduction in the total cost.



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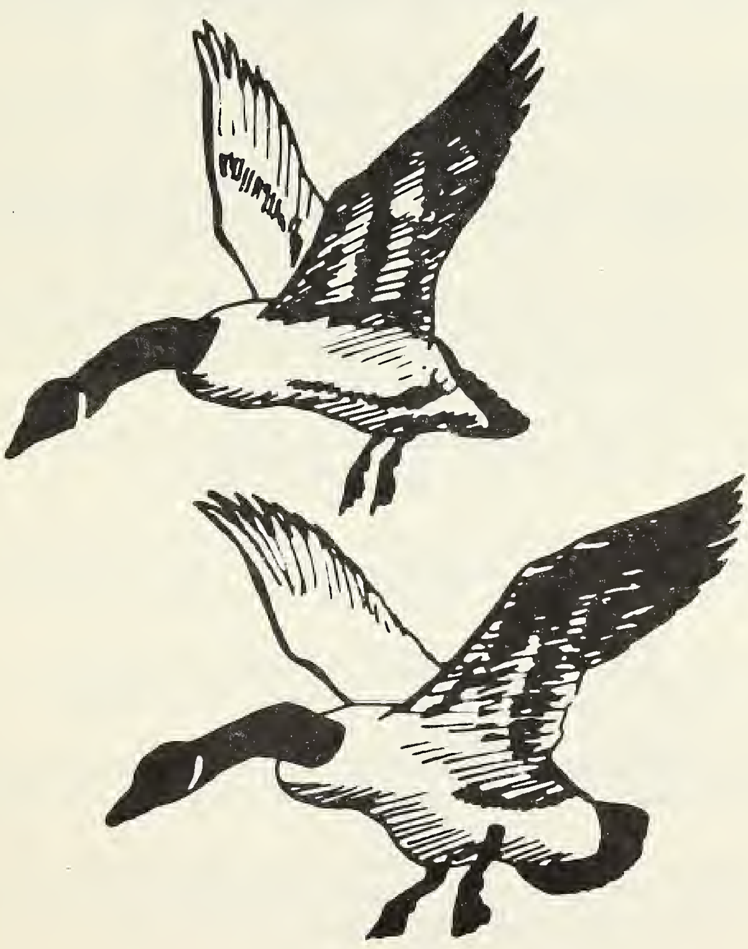

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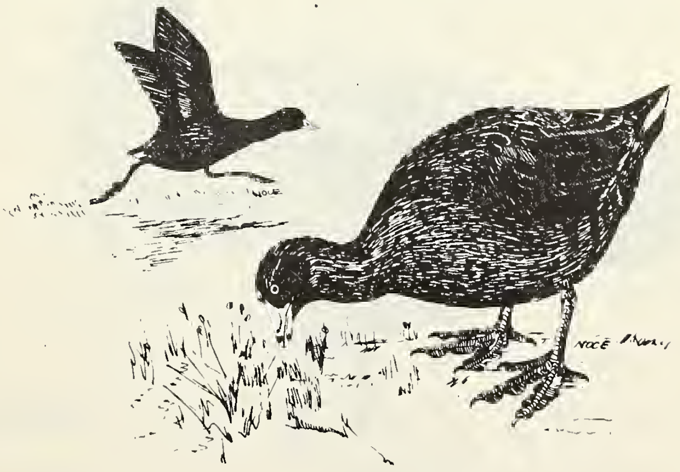
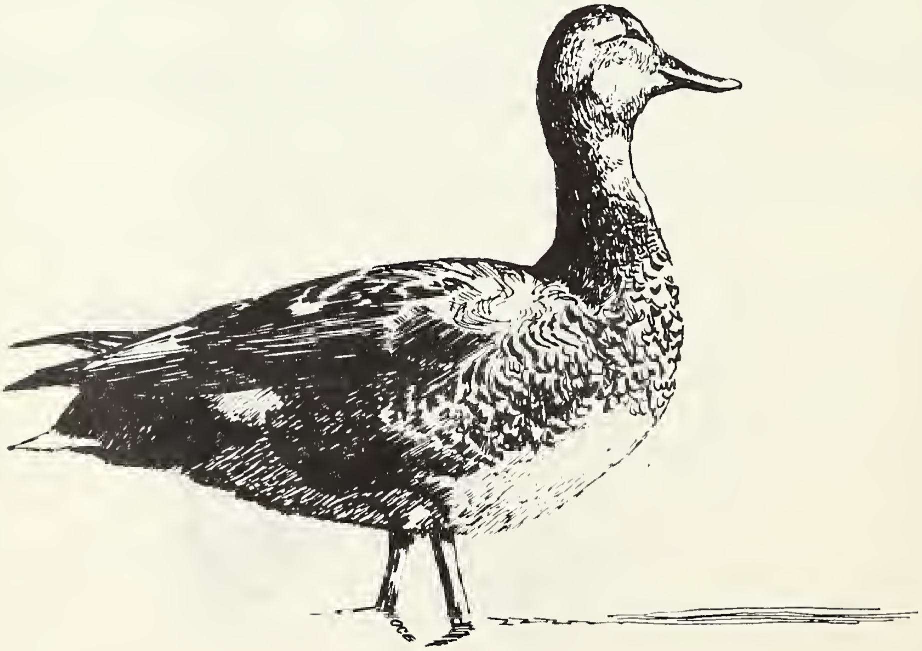


APPENDIX 1

To standardize the inventory of private duck clubs a field data sheet was developed. As the inventory progressed the format of the field data sheet changed somewhat, primarily so that data could be quantified as much as possible.

Appendix 1A presents an example of a field data sheet which illustrates the type of information that was obtained.

Appendix 1B defines the classifications used to indicate the condition of water distribution systems and levees and the results of seeding various waterfowl food plants.



APPENDIX 1A

SUISUN RESOURCE CONSERVATION DISTRICT

SUISUN MARSH INVENTORY DATA SHEET

Investigator *Ronald F. Schultze* Date *6/1/73*

Club Name *Suisun Marsh Duck Club ** (*x*) Cooperator ( ) Non-Cooperator

Location *Chadbourne Road at Chadbourne Slough*

I. Physical Features

A. Total Area (ac.) *380*

B. Upland Area (ac.) *100*

C. Tidal Area (ac.) *14*

D. Ponded Areas (No.) *2*

	Area(ac.)	Av. Depth(ft.)	Volume(ac.ft.)
1. Annually flooded	*266*	*0.66*	*177*
2. Permanently flooded	*0*		

E. Water Distribution System - Ditches and Sloughs

	Length(ft.)	Width(ft.)	Depth(ft.)	Volume(ac.ft.)	Condition
1. Main	*7,524*	*8*	*3*	*4.14*	*2*
2. Circulation	*2,970*	*6*	*2*	*0.81*	*2*
3. Sloughs	--	-	-	-	-

F. Flooding and Draining Time

1. Flooding time (days) *6*

2. Draining time (days) *27*

G. Levees

	Length(ft.)	Height(ft.)	Top Width(ft.)	Condition *
1. Exterior	*23,166*	*8*	*13.5*	*2*
2. Interior	*3,828*	*4*	*9*	*2*

H. Blinds (number) Single *3* Double *6*

* The data on this form is used as an illustration and does not reflect conditions on any particular club in the Suisun Marsh.

I. Water Control Structures

Location	Year Installed	Type 1/	Size: Length (ft.) or HP	Size: Dimension or Diameter	Control Mechanism 2/	Purpose 3/	Remarks
A	Unknown	CMP	45	36"	I-Flap O-Slide and Flap	Flood	Flapgate outside Needs repair
B	Unknown	RB	40	4'x4'	I and O Flap	Drain	Needs repair or replacement, opens by pulley
C	1972	CMP	45	36"	I-Slide O-Flap	Drain	Good condition
D	Unknown	RB	40	4'x4'	I and O Flap	Flood	Needs repair or replacement, opens by pulley

1/ CMP - Corrugated Metal Pipe, RB - Redwood Box, Pump

2/ I - Inside end of pipe, O - Outside end of pipe; flapgate, slidegate, dual, riser, open

3/ Flood, drain, dual

II. Management

A. Water

1. Follows SCS Water Management Schedule *No*

2. If not, describe: *Flood during season, some circulation of water, some dead ponds needing ditches, drain at end of season. Club recently planned will follow recommended schedule as soon as needed improvements are completed.*

B. Seeding

	Species	Rate (lb./ac.)	Area (ac.)	Results
1.	*Watergrass*	*30*	*100*	*3*
2.				
3.				

C. Other management practices (circle)

Burning Discing Herbicides Mowing

Explain: *Mow around blinds to open up pond*

III. Vegetation (Percent Area) Area (ac.) *380*

Bare ground	*3*	Olney bulrush	*0*
Alkali bulrush	*33*	Pickleweed	*24*
Blatic rush	*2*	Sago pondweed	*0*
Brass buttons	*5*	Salt grass	*7*
Cattail	*1*	Tule	*Less than 1*
Curly dock	*6*	Upland grasses	*9*
Fat hen	*8*	Thistle	*Less than 1*
		Radish	*Less than 1*

IV. Other Information

A. Members (number) *12*

Guests (number) *Unk.*

B. Type of use (circle)

Hunting   Fishing   Other Recreation   *Exercise dogs, Barbecues*

C. Economics

1. Annual cost of operation *$5,600*

2. Annual cost of maintenance *$10,000*

3. Income (Annual dues, membership fee, etc.) *$12,000*

(Livestock grazing, gas wells, etc.) *$5,000*

V. Soils

Soil type	*Reyes scl*	*Tamba mc*	
Area	*240 ac.*	*140 ac.*	

VI. Additional Remarks

Club purchased last year.

Main levee overtopped last winter at Chadbourne Slough. Just completed rebuilding portion of damaged levee.

Have equipment to construct spreader ditches to dead ponds. Will do this year.

Keeper housed on club. Maintains club and operates water control structures.

* Footnote: Condition and Results catagorized as:
1. Excellent 2. Good 3. Fair 4. Poor

APPENDIX IB

DEFINITIONS OF CONDITION AND RESULTS

I - Water Distribution (condition)

1. Excellent - Ditches developed for good water circulation; no vegetation, etc. to impede flow of water.

2. Good - Ditches generally in good shape, some vegetation or other conditions which do not allow unimpeded circulation of water.

3. Fair - Ditches overgrown with vegetation which impedes flow of water, or lack of circulation ditches in some areas.

4. Poor - Ditches overgrown with vegetation and/or lack circulation ditches in most areas and very little water circulation.

II - Levees (condition)

1. Excellent - Low growing vegetation or rock rip-rap on sides of levees to prevent erosion, top of levee in good condition allowing vehicles to be driven on top and inspection, no muskrat burrows, cracks, levee not composed of high organic soils.

2. Good - Levees generally in good shape; may have some undesirable vegetation, but minor in extent; can drive on levee; some cracks or muskrat holes, but repairable with minor effort.

3. Fair - Numerous areas needing repair due to low spots, cracks or holes, vegetation overgrowth which prevents easy access for inspection and repair; some erosion occurring. Some seepage possibly due to organic content, holes near top, etc.

4. Poor - Levee overgrown with vegetation preventing access for inspection or repair, numerous holes, cracks, etc. allowing periods of uncontrolled water flow or potential for uncontrolled flooding without major repair.

III - Management - Seeding (results)

1. Good - Good stands of vegetation established, seed formation good, natural reseeding may occur.

2. Fair - Some stands developed, some seed formation.

3. Poor - Unsuccessful germination or only small success, very little seed formation or none.

APPENDIX 2

Common and Scientific Names of Animal Species Appearing in the Suisun Marsh Report

Insects

Common Name	Scientific Name
Pasture Mosquito	*Aedes dorsalis*
Encephalitis Mosquito	*Culex tarsalis*

Fish

Carp	*Cyprinus carpio*
Mosquitofish	*Gambusia affinis*
Striped Bass	*Morone saxatilis*

Birds

Mallard	*Anas platyrhynchos*
Pintail	*Anas acuta*
Gadwall	*Anas strepera*
Cinnamon Teal	*Anas cyanoptera*
Canvasback	*Aythya valisineria*
Ring-necked Pheasant	*Phasianus colchicus*
California Black Rail	*Laterallus jamaicensis coturniculus*
California Clapper Rail	*Rallus longirostris obsoletus*

Mammals

Raccoon	*Procyon lotor*
Mink	*Mustela vison*
River Otter	*Lutra canadensis*
Salt Marsh Harvest Mouse	*Reithrodontomys raviventris*
Muskrat	*Ondatra zibethica*

APPENDIX 3

RECOMMENDED WATER MANAGEMENT FACILITIES FOR A 300 ACRE DUCK CLUB

A model duck club was developed to illustrate recommended facilities needed for proper water management (Figure 1). This duck club does not necessarily represent conditions found on most duck clubs in the Suisun Marsh in that few clubs are rectangular in shape, but modifications could be made to fit the majority of the clubs.

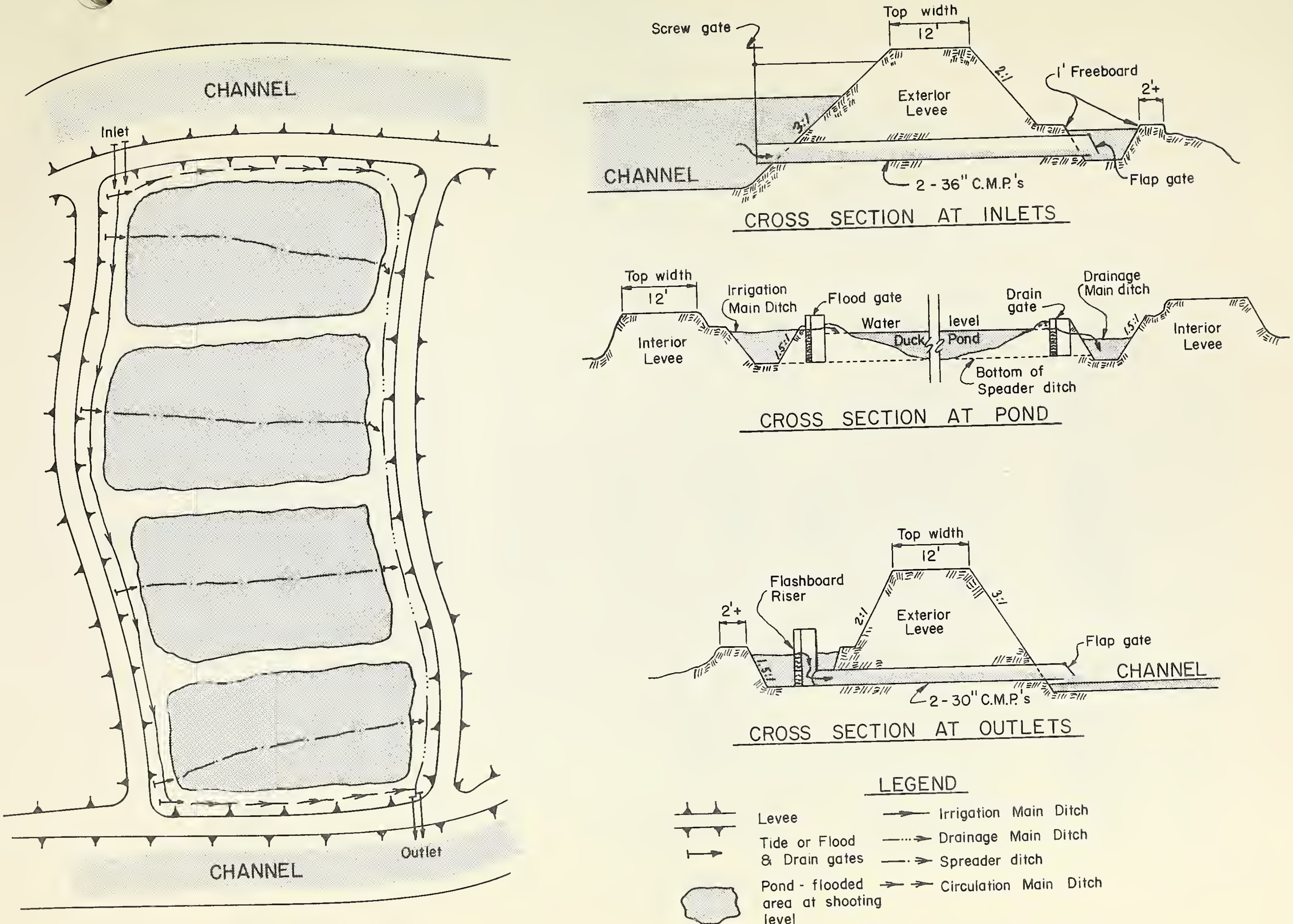
To reflect the average size of the Suisun Marsh duck clubs the area of the model was assumed to be 300 acres with approximately 70 percent of the club being flooded (210 acres). Also, the average pond water depth was assumed to be 1.25 feet, as was found on the seasonally flooded clubs sampled in the Marsh.

LEVEES

Levees are constructed to provide protection from tidal influences and/or better utilization of water management facilities. Thus, it is imperative that levees be constructed with adequate materials and in a manner to provide optimum protection from erosion, excessive seepage, and major shrinkage from inadequate compaction, unfirm foundation or decomposition of organic material (Figure 2). The top width of perimeter levees should be constructed and maintained to allow accessibility of vehicles and equipment for inspection and maintenance. These levees should have a minimum top width of 12 feet. Side slopes should be flat enough to prevent excessive erosion--landward slopes if at least 2:1 slope and tidewater slopes or slopes receiving extensive wave action should be 3:1 or flatter.

Berms should be left between levees and adjacent ditches with sufficient width to minimize the hazard to the levee due to piping through the foundation. For fill height of 6 feet or less the minimum berm width should be 10 feet; for height greater than 6 feet, at least 15 feet of berm should be left and on organic soils a minimum berm width of 25 feet should be provided. For levees where the design water depth is more than 5 feet, the land side ditch or borrow pit should be far enough away from the levee so that a line drawn between the point of intersection of the design water line with the water side of the levee and the land side toe of the levee meeting minimum dimensional requirements shall not intersect the ditch or borrow pit cross section (Figure 2).

An adequate protective cover of grasses or similar vegetation is necessary to protect against erosion by flood flows, wave action or from rainfall and runoff on the levee. Riprap may be necessary to control erosive velocities of waters on tidal slopes of certain levees.

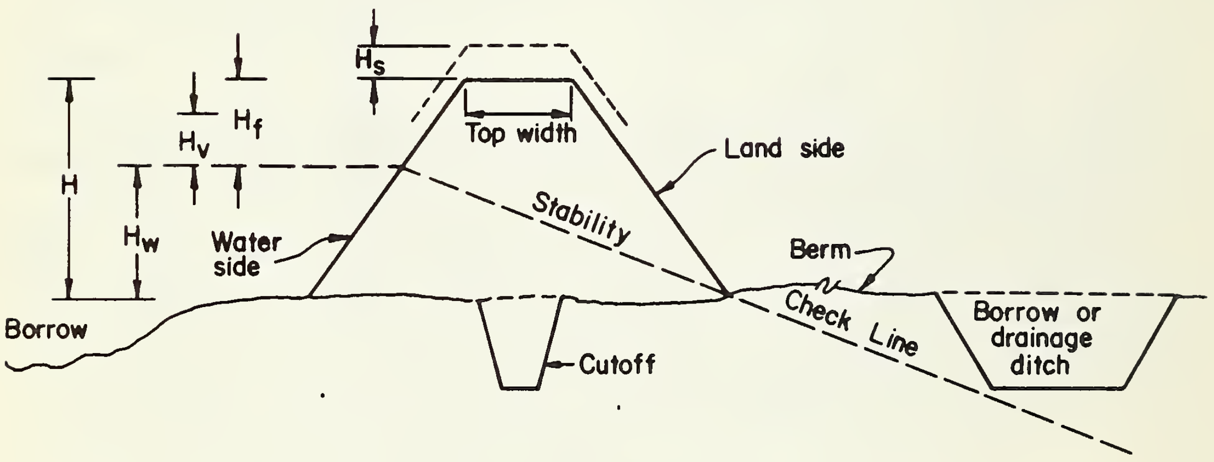


EXAMPLE OF RECOMMENDED WATER MANAGEMENT FACILITIES FOR A 300 ACRE DUCK CLUB

Figure I append.

Figure 2

SECTION THROUGH DIKE



The design height of the dike (H) will be the sum of the design high water storage (H_w), the added height (H_v) for wave action, if any, and the freeboard (H_f). The constructed height will include an allowance for settlement (H_s), which will depend on the foundation and material used in construction. The actual design high water stage should be based on the water surface profile.

The maintenance of levees must include periodic removal of woody vegetation which may become established on the embankment.

A cutoff trench, if planned, should be excavated approximately along the centerline of the levee. This excavation should be backfilled with the least permeable soil available and compacted.

The foundation area of all levees should be cleared of trees, stumps, logs, roots, brush or organic matter which would interfere with the scarifying of the area.

INLET STRUCTURES

The inlet gates should consist of a sliding or screw gate connected to the tidal channel end of a corrugated metal pipe which should be asphalt coated for protection against corrosion. A flap gate on the duck club end of the pipe is necessary for water flow control through the structure. A ramp positioned above the high tide level and attached to a bulkhead provides access to the screw gate control wheel.

DITCHES

The irrigation main ditch should be designed to carry the volume of water necessary to flood the ponds within the recommended 10 day period with at least a one-foot freeboard. Side slopes should be 1 1/2:1 or flatter.

The spreader ditches should be large enough to similarly supply their respective ponds. It is usually desirable to design them at least large enough to allow boats to move through them for access to blinds. The bottom of the ditch should be at least as low as the lowest portion of the pond to allow complete drainage.

The drainage main ditch should be designed with a minimum capacity to drain all water within 20 days. The bottom of the ditch should be at least as low as the bottom of the spreader ditches.

Circulation main ditches connecting the irrigation main ditch and drainage main ditch are desirable to allow water circulation in the main ditches separate from the ponds for about one month prior to filling ponds. This is necessary to eliminate damage to fish populations and reduce salinity levels in the ditches before flooding ponds. Control structures should be installed so that water will be forced through the ponds when they are flooded providing for better circulation in the ponds.

Flashboard weirs or similar structures may be advisable at the inlets and outlets for each pond. This will allow some individual water level control in each pond. This is particularly useful where large areas of the property are higher than others.

OUTLET STRUCTURES

An outlet water control structure which consists of a flashboard riser on the duck pond side and a flapgate on the tidal channel end of the pipe is recommended. This allows for automatic water control which takes care of excess water, as during heavy rains, and eliminates manual adjustments as is needed with screw gate outlets. The bottom of the outlet structure should at least be as low as the bottom of the drainage main ditch to allow complete removal of water.

Some clubs which have ponds that are below 0.0 elevation may more efficiently remove water utilizing a pump outlet. This provides a more positive control of water when tides do not reach levels low enough for adequate water removal through a tide gate system.

Conversely, higher clubs make better use of an inlet pump to supply water if the pond levels are above necessary levels for a tidal water control system.

APPENDIX 4

MORPHOLOGY AND CLASSIFICATION OF THE SOILS OF THE SUISUN MARSH

The influence of the soil forming factors varies within the Suisun Marsh resulting in the several different kinds of soils. Each soil is separated from other soils by morphological characteristics which can be observed and measured. The processes which have had the greatest influence in the development of the different soil morphological features are: (1) weathering of parent material, (2) accumulation and decomposition of organic matter, and (3) translocation of mineral and organic products.

The soil forming factors and diagnostic features for classifying the Suisun Marsh soils are shown in Table 1 and Table 2. The morphological features or characteristics and their effect upon their placement in the Orders, Groups, and Subgroups of the classification system are briefly described as follows:

Inceptisols

These soils are usually recent to young and show evidence of slight alteration of the parent material but lack alluvial horizons. The Inceptisols found in the Marsh fall into the Group of Haplaquepts and the Subgroup Fluventic.

The Haplaquepts are somewhat poor to very poorly drained soils on alluvial fans or marshes. Brown mottles occur within 20 inches of the surface. The Fluventic Haplaquepts are stratified and have darkened buried surface horizons that have accumulated organic matter.

The Reyes, Tamba and Valdez soils are classified in the family of Fluventic Haplaquepts.

Histosols

These soils are saturated with water for prolonged periods or artifically drained, and have 30 percent or more organic matter. The Histosols of the Suisun Marsh consist of two Groups divided into three Subgroups.

The Medihemists are organic soils saturated with water for 6 months or more of the year, or have artificial drainage. The organic matter is intermediately decomposed. The Typic Medihemists have less than one-third of the control section undecomposed and less than one-third of the control section well decomposed. The Suisun soil is classified in this Subgroup.

The Medisaprists are organic soils saturated with water for 6 months or more of the year, or have artifical drainage.

TABLE 1. SOIL FORMING FACTORS FOR SUISUN MARSH SOILS

Soil Series	Drainage & Physiography	Parent Material	Age	Vegetation
Joice	Very poorly drained	Hydrophytic plants	Recent	Hydrophytic plants
Joice Variant	Very poorly drained	Hydrophytic plant remains and mixed alluvium	Recent	Hydrophytic plants
Reyes	Poorly drained	Mixed alluvium	Young	Salt tolerant grasses & forbs
Suisun	Very poorly drained	Hydrophytic plant remains	Recent	Hydrophytic plants
Tamba	Very poorly drained	Hydrophytic plant remains and mixed alluvium	Recent	Hydrophytic plants
Valdez	Somewhat poorly drained alluvial fans	Mixed alluvium	Recent	Grasses & forbs

TABLE 2. DIAGNOSTIC FEATURES OF SUISUN MARSH SOILS

Soil Series		Diagnostic Features
Joice	-	Control section has a sapric horizon with 30-50% organic matter and a pH of more than 5.5 in some part of control section.
Joice Variant	-	Control section has a sapric horizon and a mineral layer more than 12 inches thick and a pH of more than 5.5 in some part of control section.
Reyes	-	Ochric epipedon, color cambic horizon, saturated with water or artifically drained, distinct mottles, organic matter decreases irregularly with depth, pH less than 5.5.
Suisun	-	Control section has Hemic horizon with over 50 percent organic matter and a pH of more than 5.5 in some part of control section.
Tamba	-	Ochric epipedon, cambic (color) horizon, saturated or artifically drained, mottled, organic matter decreases irregularly with depth, fine control section.
Valdez	-	Ochric epipedon, cambic (color) horizon, saturated with water or artifically drained, mottled, organic matter decreases irregularly with depth.

The organic matter is well decomposed. The Typic Medisaprists have less than one-sixth of the control section undecomposed and less than one-third of the control section intermediately decomposed and have no mineral layer 12 inches or more thick in the control section. The Joice soil is classified in this Subgroup. The Terric Medisaprists have a mineral layer 12 inches or more thick in the control section. The Joice Varient is classified in this Subgroup.

The classification of the soils of the Suisun Marsh is summarized in Table 3.

Marshland Areas High in Organic Matter

Criteria for the mapping of tidal marshes is based on a control section of 12 to 40 inches. In classifying these soils the dominant organic matter percentage of the control section is used as well as the organic matters state of decomposition. The following decomposition groups are used:

Muck (Sapric) - Highly decomposed

Peaty muck (Lenic) - Intermediate state of decomposition.

The breakdown regarding type is as follows:

Mineral texture only. (e.g., Reyes clay)	Soils with less than 15% organic matter.
Organic constituent followed by mineral texture. (e.g., Tamba mucky clay)	Soils with 15 to 30% organic matter.
Mineral texture followed by organic constituent. (e.g., Joice clayey muck)	Soils with 30 to 50% organic matter.
Organic constituent only. (e.g., Suisun peaty muck)	Soils with over 50% organic matter.

Soil Salinity

A saline soil contains enough salts distributed in the profile to interfere with the growth of most commonly grown crops. Terms used are as follows:

Moderately saline -	Plant growth moderately affected. Estimated conductance 8 to 15 mmhos/cm.
Strongly saline -	Plant growth severely affected. Estimated conductance greater than 15 mmhos/cm.

TABLE 3. CLASSIFICATION OF SUISUN MARSH SOILS

ORDER	GROUP	SUBGROUP	FAMILY	SERIES
Inceptisols	Haplaquepts	Fluventic Haplaquepts	Fine-silty, mixed, non acid, thermic	Valdez
			Fine, mixed, acid, thermic	Tamba
			Fine, mixed, sulfureous, acid, thermic	Reyes
Histisols	Medihemists	Typic Medihemists	Euic, thermic	Suisun
	Medisaprists	Typic Medisaprists	Euic, thermic	Joice
		Terric Medisaprists	Clayey, mixed, euic, thermic	Joice variant

Drainage Classes

Drainage refers to the internal soil drainage or wetness of profiles based upon observations of free water on the surface or at different depths, and those morphological characteristics of profiles that are affected by different degrees of aeration within the profile (i.e. mottling or gleying). The following terms are used as part of the mapping unit name when it is necessary for a phase separation:

Moderately well drained
Somewhat poorly drained
Poorly drained
Very poorly drained.

DESCRIPTIONS OF THE SOILS OF THE SUISUN MARSH

The following are detailed descriptions of representative profiles of the different soil series and mapping units in the Suisun Marsh Study area. Each of the mapping units are shown on the detailed soil map (Plate 1) bounded by lines and identified by a letter symbol. The first capital letter of the soil map symbol is the first letter of the soil series name. The following lower case letter is used to separate soil types or phases of the soil series.

<u>Example</u>

Map Symbol	Mapping Unit Name
Ja	Joice muck
Jb	Joice muck, clay subsoil variant

Soils that have profiles almost alike make up a soil series. All the soils of one series have major horizons that are similar in thickness, arrangement, and other important characteristics. Each soil series is named for a town (i.e. Suisun) or other geographic features (i.e. Joice) near the place where a soil of that series was first observed and mapped. Many soil series contain soils that are alike except for texture of their surface layer. According to this difference in texture, separations called soil types are made. Within a series, all the soils having surface layers of the same texture belong to one soil type.

Some soil types vary so much in slope, or some other feature affecting their use, that practical suggestions about their management could not be made if they were shown on the soil map as one unit. Such soil types are divided into soil phases. The name of a soil phase indicates a feature that affects management. In the example shown above, Joice muck, clay subsoil variant is a phase of Joice muck.

The soil map (Plate 1) was prepared from aerial photographs. They are used for base maps because they show all the topographic features and other details that help in drawing soil boundaries accurately. The area within a line designation on the soil map is called a mapping unit. On most maps detailed enough to be useful in planning management of soil and water resources, a mapping unit is nearly equivalent to a soil type or a phase of a soil type. It is not exactly equivalent, because it is not practical to show on such a map all the small, scattered bits of soil of some other kind that have been seen within an area that is dominantly of a recognized soil type or soil phase.

The best use of soil survey information can be made only where there is full realization of the limitations in collecting the soil facts. Soils are highly variable. They vary a great deal from place to place. Boundaries between different kinds of soil as shown on the soil survey map seldom are sharp or clear cut. Usually they are transitional or gradually grade into one another. This is due to processes of soil formation that alter the parent material.

Each soil profile also has a range in characteristics or variations from formal concepts of the individual soil series. In the following discussion of each soil series, the range in characteristics and inclusions of other mapping units are described in detail.

JOICE SERIES

The Joice series consists of very poorly drained organic soils with high mineral sediment content. The soils occupy nearly level salt water marshes and are formed from hydrophytic plant remains mixed with fine mineral sediments from mixed sources. The vegetation is dominantly perennial herbs and sedges. Elevations range from minus 5 feet to sea level. Suisun and Tamba are the principal associated soils.

In a typical profile the surface soil is black, saline, clayey muck 20 inches thick. The subsoil is black, saline, clayey muck 20 inches thick. The substratum is black, saline, clayey muck that extends to a depth greater than 60 inches.

Joice soils are used for wildlife, recreation, and pasture.

Joice clayey muck (Ja)

This soil occurs on nearly level salt water marshes with slopes of less than one percent.

Representative profile: Southwest corner of northwest 1/4 Section, T4N, R1W (projected) Mount Diablo Base Meridian, about 5 1/2 miles south of Fairfield, Solano County, California.

0-7" Clayey muck, organic matter 45 percent, fibers 5 percent; 50 percent of fibers are greater than 1 mm; natural fibers dark brown (7.5YR 3/2), matrix black (10YR 2/1), pressed firmly black (10YR 2/1), rubbed gently black (10YR 2/1), when dry black (10YR 2/1); weak medium crumb structure; very hard, nonsticky, slightly plastic; dusty; very strongly acid (pH 4.5).

7-20" Clayey muck, organic matter 40 percent, fibers 20 percent 50 percent of fibers are greater than 1 mm; natural fibers dark brown (7.5YR 3/2), matrix black (5YR 2/1), pressed firmly black (5YR 2/1), rubbed gently black (10YR 2/1), gray (N 6/) with few medium prominent black mottles (N 2/)

when dry; massive; extremely hard, sticky, slightly plastic; 50 percent ooze, turbid; dusty; very strongly acid (pH 5.0).

20-40" Clayey muck, organic matter 35 percent, fibers 25 percent; 50 percent of fibers are greater than 1 mm; natural fibers dark brown (7.5YR 3.2); matrix very dark gray (10YR 3/1) pressed firmly very dark gray (10YR 3/1), rubbed gently very dark brown (10YR 2/2), mottled gray and black (N 6/ & N 2/) with few fine prominent yellowish brown (10YR 5/8) mottles when dry; massive; extremely hard, slightly sticky, slightly plastic; 75 percent ooze, turbid; dusty; very strongly acid (pH 5.0).

40-60" Clayey muck, organic matter 35 percent, fibers 60 percent; 60 percent of fibers are greater than 1 mm; natural fibers dark brown (7.5YR 3/2), matrix very dark gray (10YR 3.1), pressed firmly mottled dark brown (7.5YR 3/2) and very dark brown (10YR 2/2), rubbed gently very dark brown (10YR 2/2), black (N 2/) with many fine prominent yellowish brown (10YR 5/8) mottles when dry; massive; extremely hard, nonsticky, slightly plastic; 60 percent ooze, turbid; dusty; moderately alkaline (pH 8.0).

The surface horizon ranges in color from very dark gray, very dark brown, to black; in texture from clayey muck to mucky clay loam; in reaction from strongly acid to very strongly acid; in thickness from 8 to 10 inches. The subsurface horizon ranges in color from very dark gray, black, to very dark brown; the texture is clayey muck with 30 to 50 percent organic matter; the reaction ranges from very strongly acid to moderately alkaline; the thickness ranges from 40 to over 50 inches. The water table varies with management of levees and tide gates but is usually less than 30 inches below the surface in mid summer and near the surface in winter months. The soils are strongly saline, the electrical conductance ranges from 15 to 48 mmhos per centimeter at 25° C. The moderately alkaline layers become acid if the soil is exposed to air and allowed to dry.

Included are small areas of Suisun peaty muck and Tamba mucky clay.

This very poorly drained soil is moderately rapid in permeability. The surface runoff is ponded and the erosion hazard is none to slight. The total available water holding capacity is 4 to 5 inches. The effective rooting depth is shallow. It has low fertility.

The soil is used mainly for wildlife and recreation. Other uses include pasture.

JOICE VARIANT

The Joice variant consists of very poorly drained organic soils over clay subsoils. The soils occupy nearly level salt water marshes and are formed from hydrophytic plant remains mixed with fine mineral sediments from mixed sources. The vegetation is dominantly perennial herbs and sedges. Elevations range from a minus 3 feet to 1 foot above sea level. Suisun and Joice are the principal associated soils.

In a typical profile the surface soil is dark gray clayey muck 7 inches thick. The subsoil is black clayey muck 22 inches thick. The substratum is gray clay that extends to a depth greater than 60 inches.

Joice variant soils are used for wildlife, recreation, and pasture.

Joice clayey muck, clay subsoil variant (Jb)

This soil occurs on nearly level salt water marshes with slopes of less than one percent.

Representative profile: Southwest corner NW 1/4 Section 4, T4N, R1W, Mount Diablo Base Meridian, about 3 miles east of Suisun City, Solano County, California.

0-7" Clayey muck, organic matter 30 percent, fibers 50 percent; 10 percent of fibers are greater than 1 mm; natural fibers brown (7.5YR 5/4), matrix dark olive gray (5Y 3/2), pressed firmly dark grayish brown (10YR 4/2), rubbed gently very dark grayish brown (10YR 3/2), dark gray (N 4/0) when dry; massive; very hard, nonsticky, slightly plastic; 10 percent ooze, turbid; dusty; neutral (pH 7.0); clear wavy boundary.

7-21" Clayey muck, organic matter 40 percent, fibers 40 ercent; 10 percent of fibers are greater than 1 mm; natural fibers brown (7.5YR 5/4), matrix very dark brown (10YR 2/2), pressed firmly very dark gray (10YR 3/1), rubbed gently very dark brown (10YR 2/2), black (10YR 2/1) when dry; massive, very hard, nonsticky, nonplastic; 15 percent ooze, turbid; dusty; slightly acid (pH 6.5); clear wavy boundary.

21-29" Clayey muck, organic matter 50 percent, fibers 45 percent; 10 percent of fibers are greater than 1 mm; natural fibers brown (7.5YR 5/4), matrix very dark brown (10YR 2/2), rubbed gently very dark brown (10YR 2/2), black (10YR 2/1) when dry; very hard, nonsticky, nonplastic; 15 percent ooze, turbid; dusty; slightly acid (pH 6.5); abrupt smooth boundary.

29-60" Gray (N 6/), clay, very dark gray (N 3/) moist; massive; very hard, slightly sticky, plastic; moderately alkaline (pH 8.2); disseminated lime, very slightly effervescent.

The surface layer ranges in color from dark gray to black, in texture from clayey muck to mucky clay loam, in reaction from strongly acid to neutral, in thickness from 5 to 8 inches. The subsurface layer ranges in color from black to very dark brown, in texture of clayey muck; the reaction ranges from slightly acid to moderately alkaline; the thickness is 23 to 28 inches. The substratum ranges in color from gray to greenish gray, in texture from clay to sandy clay, the reaction is moderately alkaline.

Included are small areas of Suisun peaty muck and Joice clayey muck.

This very poorly drained soil has moderately rapid permeability. The surface runoff is ponded and the erosion hazard is none to slight. The total available water holding capacity is 4 to 5 inches. The effective rooting depth is shallow. The natural fertility is low.

This soil is used for wildlife and pasture. Other uses include recreation.

REYES SERIES

The Reyes series consists of poorly drained, fine textured soils that are very strongly acid and saline. The soils occupy salt water marshes and are formed from mixed alluvium from mixed sources. The vegetation is salt tolerant grasses and forbs. Tamba is the principal associated soil.

In a typical profile the surface soil is light gray, yellowish red and grayish brown mottled, silty clay 7 inches thick. The subsoil is gray, mottled, silty clay 35 inches thick. The substratum is gray moderately alkaline silty clay that becomes strongly acid if exposed to air and allowed to dry.

Reyes soils are used for wildlife, recreation, and dry farmed oats.

Reyes silty clay (Re)

This soil occurs on nearly level salt water marshes with slope of less than one percent.

Representative profile: Northwest corner NE 1/4 Section 18, T3N, R1E (projected), Mount Diablo Base Meridian, 1 3/4 miles north, 2 1/4 miles west of Collinsville, Solano County, California.

Ap1 0-3" Mottled, light gray and yellowish red (10YR 6/1, N 6/ , 5YR 5/6) silty clay; mottled, dark reddish brown, yellowish red and grayish brown (5YR 3/4, 5YR 4/6, 10YR 5/2) moist; strong medium angular blocky structure; hard, firm, sticky, plastic; abundant fine and very

		fine roots; many fine and very fine tubular pores; strongly acid (pH 5.5); clear smooth boundary.
Ap2	3-7"	Grayish brown (2.5YR 5/2) silty clay with few fine distinct reddish brown (5YR 5/4) mottles; grayish brown (10YR 5/2) moist; strong medium angular blocky structure; hard, firm, sticky, plastic; many fine and very fine roots; many fine and very fine tubular pores; very strongly acid (pH 4.5); diffuse wavy boundary.
B21	7-16"	Gray (10YR 5/1) silty clay with common medium prominent reddish brown (5YR 5/4) mottles; grayish brown (10YR 5/2) with many large prominent dark reddish brown (5YR 3/4) and yellowish red (5YR 4/6) mottles moist; strong medium and coarse angular blocky structure; hard, firm, sticky, plastic; many fine and very fine roots; common fine and very fine tubular pores; very strongly acid (pH 4.5); diffuse wavy boundary.
B22	16-42"	Gray (10YR 5/1) silty clay, dark gray (10YR 4/1) moist; strong coarse prismatic structure; firm, sticky, plastic; many fine and very fine roots; common fine and very fine tubular pores; very strongly acid (pH 4.5); diffuse wavy boundary.
C1	42-62"	Gray (N 5/) silty clay, dark gray (N 4/) moist; weak coarse prismatic structure; sticky, plastic; common fine roots; common fine tubular pores; very strongly acid (pH 4.5); diffuse wavy boundary.
C2	62"+	Gray (N 5/) silty clay, dark gray (N 4/) moist; massive; sticky, plastic; few fine roots; very few tubular pores; moderately alkaline (pH 8.0).

The A horizon has a wide range of mottled colors which include light gray, gray, light brownish gray, very pale brown, brownish yellow, and yellowish red; texture ranges from clay to silty clay; reaction ranges from medium to extremely acid. The thickness of the A horizon ranges from 5 to 11 inches. The B2 horizon is gray to light gray, mottled, clay or silty clay that ranges from strongly acid to extremely acid. The B2 horizon ranges from 28 to 40 inches in thickness and may or may not have strata of organic matter. The C horizon ranges in color from gray to bluish gray clay or silty clay, in reaction from extremely acid to moderately alkaline.

Included are small areas of Tamba mucky clay and Valdez silty clay loam.

This poorly drained soil has slow permeability. The surface runoff is ponded and the erosion hazard is none to slight. The total available water holding capacity is 3 to 5 inches.

The effective rooting depth is moderately deep. The soil has very low natural fertility.

This soil is used mainly for wildlife and recreation. Other uses include pasture.

SUISUN SERIES

The Suisun series consists of very poorly drained organic soils. The soils occupy nearly level salt water marshes and are formed from hydrophytic plant remains mixed with fine mineral sediments from mixed sources. The vegetation is dominantly perennial herbs and sedges. Elevations range from minus 5 feet to sea level. Joice is the principal associated soil.

In a typical profile the surface soil is black with dark reddish brown fibers, muck, 18 inches thick. The subsoil is black to very dark gray with dark reddish brown fibers, peaty muck, 20 inches thick. The substratum is very dark gray with reddish brown fibers, peaty muck, and extends to a depth greater than 60 inches.

Suisun soils are used for wildlife, recreation, and pasture.

Suisun peaty muck (Sp)

This soil occurs on nearly level salt water marshes with slopes of less than one percent.

Representative profile: 7/8 mile west, 3/8 mile north of boat ramp located at east side of Grizzly Island on Montezuma Slough. The boat ramp is located about 1 3/4 miles north and 2 1/4 miles west of Collinsville, Solano County, California.

0-9" Muck, organic matter 50 percent, fibers 5 percent; 60 percent of fibers are greater than 1 mm; dark reddish brown (5YR 3/2) natural fibers, black (10YR 2/1) matrix, black (10YR 2/1) pressed firmly, black (10YR 2/1) gently rubbed, very dark gray (10YR 3/1) when dry with many prominent light gray and yellowish brown (10YR 6/1, 5/8) mottles; massive; hard, slightly sticky, slightly plastic; turbid; dusty; very strongly acid (pH 5.0).

9-18" Peaty muck, organic matter 70 percent, fibers 40 percent; 40 percent of fibers are greater than 1 mm; dark reddish brown (5YR 3/2) natural fibers, black (10YR 2/1) matrix, black (10YR 2/1) pressed firmly, black (10YR 2/1) rubbed gently, black (10YR 2/1) when dry; massive; hard, nonsticky, slightly plastic; turbid; dusty; very strongly acid (pH 5.0).

18-28" Peaty muck, organic matter 60 percent, fibers 70 percent; 70 percent of fibers are greater than 1 mm; dark reddish brown (5YR 3/3) natrual fibers, black (10YR 2/1) matrix, mixed black, very dark gray and dark brown (10YR 2/1, 3/1, 3/3) pressed firmly, black (10YR 2/1) rubbed gently, black and brown (10YR 2/1, 4/2) when dry; massive, hard, nonsticky, nonplastic; turbid; dusty; moderately alkaline (pH 8.2) becoming strongly acid (pH 5.4) on exposure to air for a few weeks.

28-38" Peaty muck, organic matter 50 percent, fibers 50 percent; 50 percent of fibers are greater than 1 mm; dark reddish brown (5YR 3/3) natural fibers, very dark gray (10YR 3/1) matrix, black (10YR 2/1) pressed firmly, mixed black and gray (10YR 2/1, 3/1) rubbed gently; black and light gray (10YR 2/1, 6/1) when dry; massive; hard, slightly sticky, slightly plastic; turbid; dusty; strongly alkaline (pH 8.5) becoming medium acid (pH 6.0) on exposure to air for a few weeks.

38-60" Peaty muck, organic matter 50 percent, fibers 40 percent; 85 percent of fibers are greater than 1 mm; dark reddish brown (5YR 3/3) natural fibers, very dark gray (10YR 3/1) matrix, black very dark gray and reddish brown (10YR 2/1, 3/1, 5YR 3/3) pressed firmly, black and very dark gray (10YR 2/1, 3/1) gently rubbed, black and light gray (10YR 2/1, 6/1) when dry; massive; hard, slightly sticky; nonplastic; turbid; dusty; strongly alkaline (pH 8.5) becoming less alkaline on exposure to air.

The surface horizon ranges in color from black, very dark gray, to very dark brown; in texture from muck to peaty muck, in reaction from medium acid to very strongly acid, in thickness from 15 to 18 inches. The subsurface horizon ranges in color from black, very dark gray, to very dark brown; the texture is peaty muck with 50 to 70 percent organic matter; the reaction ranges from mildly alkaline to strongly alkaline, in thickness from 42 to over 45 inches. The water table varies with management of levees and tide gates but is usually less than 30 inches below the surface in mid summer and near the surface in winter months. The soils are strongly saline, the electrical conductance ranges from 15 to 50 mmhos per centimeter at 25° C. The moderately alkaline layers become acid if exposed to air and allowed to dry.

Included are small areas of Joice clayey muck, and Tamba mucky clay.

This very poorly drained soil is rapidly permeable. The surface runoff is ponded and the erosion hazard is none to slight. The total available water holding capacity is 4 to 5 inches. The effective rooting depth is shallow. This soil has low fertility.

This soil is used mainly for wildlife and recreation. Other uses include limited pasture.

TAMBA SERIES

The Tamba series consists of very poorly drained, fine textured soils with high organic matter. The soils occupy nearly level salt water marshes and are formed in mixed alluvium from mixed sources and hydrophytic plant remains. The vegetation is dominantly perennial sedges and herbs. Elevations range from minus 3 feet to sea level. Joice and Reyes are the principal associated soils.

In a typical profile, the surface soil is light brownish gray, mottled, mucky clay 10 inches thick. The subsoil is mottled, black and gray mucky clay 42 inches thick. The substratum is gray mucky clay that extends to a depth greater than 60 inches.

Tamba soils are used for wildlife, recreation, and pasture.

Tamba mucky clay (Ta)

This soil occurs on nearly level salt water marshes with slopes of less than one percent.

Representative profile: 5/8 mile west of boat ramp located at east side of Grizzly Island on Montezuma Slough. The boat ramp is about 3/4 miles north and 2 1/4 miles west of Collinsville, Solano County, California.

Ap1 0-5" Light brownish gray (10YR 6/2) mucky clay with common medium distinct light yellowish brown (10YR 6/4) mottles, very dark grayish brown (10YR 3/2) moist; weak fine and medium crumb structure; slightly hard, friable, sticky, plastic; many micro and very fine roots; many micro and very fine pores; strongly acid (pH 5.5); clear smooth boundary.

Ap2 5-10" Mottled grayish brown and yellowish brown (10YR 5.2, 5/4) mucky clay, mottled very dark brown and dark yellowish brown (10YR 2/2, 3/4) moist; weak fine and weak crumb structure; slightly hard, friable, slightly sticky, slightly plastic; common micro and very fine roots; common micro and very fine pores; very strongly acid (pH 4.5); abrupt smooth boundary.

B21 10-31" Gray (N 6/) and black (10YR 2/1) mucky clay with few fine prominent yellowish red (10YR 5/8) mottles, black (10YR 2/1) with few fine prominent dark red (2.5YR 3/6) mottles moist; massive; slightly hard, friable, sticky, plastic; common micro and very fine roots; common micro and very fine pores; very strongly acid (pH 4.5); diffuse wavy boundary.

B22 31-52" Gray (N 6/) and black (10YR 2/1) mucky clay with few fine prominent brown (7.5YR 3/2) mottles, very dark brown (10YR 2/2) with few fine distinct dark brown (7.5YR 3/2) mottles moist; massive; slightly hard, friable, sticky, plastic; few micro and very fine roots; common micro and very fine pores; very strongly acid (pH 4.5); gradual wavy boundary.

B23 52-78" Gray (N 6/) mucky clay, dark greenish gray (5BG 4/1) moist; massive; slightly hard, firm, very sticky, plastic; many fine tubular pores; moderately alkaline (pH 8.0), strong odor of H_2S, becomes acid when exposed to air for a few weeks.

The A horizon ranges in color from gray, light gray, light brownish gray, to grayish brown; in texture from clay to mucky clay, in reaction from medium to very strongly acid; in thickness from 8 to 15 inches. The B horizon ranges in color from gray to black with prominent mottles; the texture is clay with 15 to 30 percent organic matter; the reaction ranges from very strongly acid to moderately alkaline; the thickness ranges from 25 to 42 inches. The C horizon ranges in color from gray to greenish gray, in texture from clay to mucky clay. The reaction is moderately alkaline but becomes acid if exposed to air and allowed to dry. The thickness ranges from 10 to over 27 inches. The water table varies with management of levees and tide gates and is near 3 feet in mid summer and near the surface in winter months. The soils are strongly saline, the electrical conductance ranges from 15 to 40 mmhos per centimeter at 25° C.

Included are small areas of Reyes silty clay, Joice clayey muck, and Suisun peaty muck.

This very poorly drained soil is moderately permeable. The surface runoff is ponded and the erosion hazard is none to slight. The total available water holding capacity is 3 to 5 inches. The effective rooting depth is shallow. This soil has low fertility.

This soil is used mainly for wildlife and recreation. Other uses include pasture.

Tidal Marsh (Td)

This miscellaneous land type consists of very wet land located between constructed levees and bodies of water. It is inundated periodically by tidal water, and ranges from mud flats covered daily by tidal flow to a mixture of hydrophytic plant remains and alluvium covered only by high tides. The vegetation is nil on the mud flats and is rushes and sedges on the areas covered less often by high tides.

The very poorly drained soil is slow in permeability. The surface runoff is very slow and the erosion hazard is none to slight. The total available water holding capacity is 1 to 2 inches. Effective rooting depth is very shallow. The fertility is very low.

This land type is used for wildlife and recreation.

VALDEZ SERIES

The Valdez series consists of somewhat poorly drained medium and moderately fine textured soils. The soils occur on nearly level alluvial fans and dredged spoil areas of mixed alluvium from mixed sources. The vegetation, where not cultivated, is annual grasses and forbs. Elevations range from near sea level to 15 feet.

In a typical profile, the surface soil is light brownish gray silty clay loam 12 inches thick. The subsoil is mottled light gray, light yellowish brown and yellowish brown stratified silty clay loam and very fine sandy loam with many large prominent mottles and 20 inches thick. The substratum is mottled light brownish gray to pale brown stratified silty clay loam, silt loam and very fine sandy loam that extends to a depth greater than 60 inches.

Valdez soils are used for forage crops, dry farmed small grain, wildlife, and recreation.

Valdez silty clay loam (Vc)

This soil occurs on nearly level alluvial fans, with average slopes of less than one percent.

Representative profile: 3/8 mile south, 1/4 mile east of California State Fish and Game Headquarters on Grizzly Island, Solano County, California.

Ap1 0-5" Light brownish gray (10YR 6/2) silty clay loam with common medium prominent strong brown (7.5YR 5/6) mottles, brown (10YR 4/3) with common medium prominent strong brown (7.5YR 4/6) mottles moist; weak fine subangular blocky structure; hard, friable, sticky, plastic, common fine and medium, many micro and very fine roots; common medium, few very fine tubular pores; slightly acid (pH 6.5); clear smooth boundary.

Ap2 5-12" Mottled light gray and yellowish brown (10YR 6/1, 5/6, 2.5YR 7/2) silty clay loam, brown (10YR 5/3) moist with common medium prominent strong brown (7.5YR 5/6) and common large prominent dark reddish brown (5YR 3/4) mottles; weak fine platy and weak medium prismatic structure; hard, friable, sticky, plastic; common fine and medium, many micro and very fine roots; common micro, few very fine tubular pores; medium acid (pH 5.8); clear smooth boundary.

B21 12-32" Mottled light gray, light yellowish brown and yellowish brown (10YR 7/1, 6/4, 5/8) stratified silty clay loam and very fine sandy loam, grayish brown, (10YR 5/2) with many large prominent strong brown and dark reddish brown mottles (7.5YR 5/6, 5YR 3/4) moist; fine platy structure in very fine sandy loam, medium angular blocky

		structure in silty clay loam; hard, firm, very fine sandy loam is nonsticky slightly plastic; silty clay loam is sticky plastic; common very fine and micro roots, common micro tubular pores; medium acid (pH 6.0); clear smooth boundary.
C1	32-42"	Light brownish gray (10YR 6/2) silty clay loam with many large prominent strong brown (7.5YR 5/6) mottles, dark grayish brown (10YR 4/2) with strong brown and reddish brown (7.5YR 5/6, 5YR 4/4) mottles moist; compound structure of strong, fine, medium, platy and moderate, medium, prismatic; hard, firm, sticky, plastic; common very fine exped; few micro tubular; medium acid (pH 6.0); clear smooth boundary.
C2	42-50"	Pale brown (10YR 6/3) silt loam with many large prominent reddish brown (5YR 4/4) mottles, brown (10YR 4/3) with many large prominent reddish brown and dark reddish brown (5YR 4/4, 3/4) mottles moist; moderate fine platy structure breaking to moderate fine angular blocky structure; hard, friable, slightly sticky, slightly plastic; few micro and very fine roots; few micro tubular pores; slightly acid (pH 6.5); abrupt smooth boundary.
C3	50-58"	Light brownish gray (10YR 6/2) very fine sandy loam with common medium distinct yellowish brown and few large prominent reddish brown (10YR 5/4, 5YR 4/4) mottles, dark grayish brown (10YR 4/2) with common medium distinct dark yellowish brown and few large prominent dark reddish brown (10YR 4/4, 5YR 3/4) mottles moist; weak fine platy structure; slightly hard very friable, nonsticky, slightly plastic; few micro and very fine roots; few micro tubular pores; medium acid (pH 5.5 - 6.0).

The A horizon ranges in color from light brownish gray, pale brown, to light gray and may have distinct to prominent mottles. The A horizon texture ranges from silty clay loam to silt loam; reaction ranges from slightly to medium acid; thickness ranges from 10 to 15 inches. The B2 horizon ranges in color from light gray to pale brown with distinct to prominent mottles; the texture is silty clay loam with thin stratas of sandy loam and silt loam. Reaction ranges from medium acid to neutral; thickness is 16 to 25 inches; salinity is slight to moderate. The C horizon ranges in color from light gray to pale olive with distinct to prominent mottles; texture ranges from silty clay loam to sandy loam; reaction ranges from slightly acid to moderately alkaline; salinity ranges from moderate to strong. The soil is typically stratified.

Included are small areas of Reyes silty clay and some areas with silty clay surface texture.

This somewhat poorly drained soil has moderately slow permeability.

The surface runoff is slow and erosion hazard is none to slight. The total available water holding capacity is 4 to 6 inches. Effective rooting depth is deep. The soil is low in fertility.

This soil is used mainly for wildlife. Other uses are dry farmed barley and recreation.

Valdez silty clay loam, clay substratum (Ve)

This soil is similar to Valdez silty clay loam except that it is underlain by a buried clay soil 35 to 50 inches below the surface. A water table fluctuates to within 3 feet of the surface during the winter months. The soil is moderately to strongly saline.

Included are small areas of Reyes silty clay and Tamba mucky clay.

This somewhat poorly drained soil has slow permeability. Surface runoff is slow and the erosion hazard is none to slight. The total available water holding capacity is 4 to 6 inches. Effective rooting depth is deep. The soil is low in fertility.

This soil is used mainly for wildlife. Other uses include pasture, dry farmed barley, and recreation.

SOIL CHARACTERISTICS AND QUALITIES

Soil Characteristics and Qualities (Table 4) which follows includes a brief description and the acreage of each of the mapping units found in the Suisun Marsh Study area. The tabular arrangement provides a quick comparison of the major soil characteristics and qualities both within and between the mapping units.

TABLE 4.--SOIL CHARACTERISTICS AND QUALITIES

SURVEY AREA Suisun Marsh - Solano County

Map Symbol	Area (Acres)	Extent (Percent)	Soil Name	Capability Unit	Position	Profile (dry) Surface Layer	Profile (dry) Subsoil	Profile (dry) Substratum or Parent Material	Natural Drainage	Subsoil Perm.	Runoff	Erosion Hazard	Effective Depth (inches)	A.W.C. [1] (inches)	Inherent Fertility	Present Land Use
Ja	14,250	25.8	Joice clayey muck	VIw10	Marsh	Black, clayey muck, saline, very strongly acid	Black, clayey muck, saline, very strongly acid	Black, clayey muck, saline, moderately alkaline	Very poor	Moderately rapid	Ponded	None to slight	12-18	4-5	Low	Water-fowl habitat
Jb	1,350	2.4	Joice clayey muck, clay substratum, variant	VIw10	Marsh	Dark gray, clayey muck, saline, neutral	Black, clayey muck, saline, strongly acid	Gray, clay, massive, moderately alkaline	Very poor	Moderately rapid	Ponded	None to slight	12-18	4-5	Low	Water-fowl habitat
Re	11,590	21.0	Reyes silty clay	VIw9	Marsh	Mottle, light gray, yellowish red, grayish brown, silty clay, strongly acid	Gray, mottled, silty clay, angular blocky, very strongly acid	Gray silty clay, massive, moderately alkaline	Poor	Show	Ponded	None to slight	20-36	3-5	Very low	Water-fowl habitat
Sp	4,920	8.9	Suisun peaty muck	VIw10	Marsh	Black with dark reddish brown fibers, muck, very strongly acid	Black to very dark gray, with dark reddish brown fibers, peaty muck, moderately alkaline	Very dark gray with reddish brown fibers, peaty muck, strongly alkaline	Very poor	Rapid	Ponded	None to slight	10-20	4-5	Low	Water-fowl habitat
Ta	14,660	26.5	Tamba mucky clay	VIw9	Marsh	Light brownish gray, mottled, mucky clay, crumb, strongly acid	Mottled, black and gray, mucky clay, massive, strongly acid	Gray, mucky clay, massive moderately alkaline	Very poor	Moderate	Ponded	None to slight	12-20	3-5	Low	Water-fowl habitat
Td	1,575	2.9	Tidal marsh	VIIIw6	Tidal marsh	Variable - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - - - - - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
Vc	5,400	9.8	Valdez silty clay loam	IIIw6	Alluvial fan	Light brownish gray, silty clay loam, subangular blocky, slightly acid	Mottled, silty clay loam, platy and subangular blocky, slightly acid	Mottled, stratified, silt loam, silty clay loam, fine sandy loam	Somewhat poor	Moderately slow	Slow	None to slight	36-60	4-6	Low	Dryland grain
Ve	1,500	2.7	Valdez silty clay loam, clay substratum	IVw6	Alluvial fan	Light brownish gray, silty clay loam, subangular blocky, slightly acid	Mottled, silty clay loam, platy and subangular blocky, slightly acid	Mottled, stratified, silt loam, silty clay loam, fine sandy loam	Somewhat poor	Slow	Slow	None to slight	36-60	4-6	Low	Dryland grain
Total Acres	55,245	100.00														

[1] Total available water holding capacity within effective soil depth.

ESTIMATED PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS

Estimates of soil properties important to engineering (Table 5) are based on field classification and descriptions, physical and chemical tests of selected representative samples, test data from comparable soils in adjacent areas and experience in working with the individual in the area.

Depth to bedrock is shown to give an indication of the presence or absence of bedrock within a five foot depth. When the depth to bedrock is noted as 5 plus it merely indicates that the distance to the bedrock is more than 5 feet.

Soils are identified by three classifications: (1) United States Department of Agriculture Texture, (2) Unified, and (3) AASHO engineering classifications. The AASHO and Unified classifications will be explained later in the engineering section. The United State Department of Agriculture textural system classifies soils based on the particles smaller than 2 mm in diameter. The percentage of sand, silt, and clay determines the textural classification of this material. The sum of the percentages of each of the soil separates, therefore, equals 100 after the gravel material has been excluded.

Percentage passing sieve sizes No. 4, 10, 40, and 200 reflects the normal range for a soil series. Most soils will fall within this range but there may be variations occurring outside. It is not to be assumed that all samples of a specific soil will fall within the range shown, nor that the engineering classification will always be as shown.

Liquid limit and plasticity index indicate the effect of water on the strength and consistence of the soil material. As the moisture content of a clayey soil increases from a dry state the material changes from a semi-solid to a plastic state. If the moisture is further increased the material changes from a plastic to a liquid state. The plastic limit is the moisture content at which the soil material passes from a semi-solid to a plastic state. The liquid limit is the moisture content at which a soil passes from a plastic to a liquid state.

The plasticity index is the numerical difference between the liquid limit and the plastic limit. It indicates the range of moisture content within which a soil material is plastic. When the liquid limit or plastic limit is equal to or higher than the liquid limit, the plasticity index is reported as non-plastic (N.P.).

Permeability of the soil relates only to the movement of water downward through undisturbed and uncompacted soil. It was estimated by comparison with soils of known permeability as described in the soil survey descriptions. It is shown as the range in which the soil

TABLE 5
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CALIFORNIA

Estimated physical and chemical properties of the soils in Suisun Marsh.

Soil series and map symbols	Depth to--		Depth from surface of typical profile	Classification			Percentage passing sieve					Atterberg values		Permeability	Available water capacity	Reaction	Salinity	Shrink-swell potential	Corrosivity uncoated steel
	Bed-rock	Season-al high water table		USDA texture	Unified	AASHO	Greater than 3 inches	No. 4	No. 10	No. 40	No. 200	Liquid limit	Plastic index						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	(Feet)	(Feet)	(Inches)											(Inches per hour)	(Inches per inch of soil)	(pH value)			
Joice (Ja)	5+	1-2	0-60	Clayey muck	Pt	A-8	Organic and Mineral Mixture							2.0-6.3	.24	4.5-5.5	Very high	High shrink low swell	Severe
Joice Variant (Jb)	5+	1-2	0-30	Clayey muck	Pt	A-8	Organic and Mineral Mixture							2.0-6.3	.24	4.5-5.5	Very high	High shrink low swell	Severe
			30-60	Clay	CL	A-6	100	100	100	90-100	75-95	20-40	15-30	<0.06	.03	7.4-8.4	Very high	High	Severe
Reyes (Re)	5+	2-5	0-60	Silty clay	CL	A-6 or A-7	100	100	100	90-100	75-95	30-50	10-30	0.06-0.2	.10	4.0-5.0	Very high	High shrink low swell	Severe
Suisun (Sp)	5+	2-3	0-60	Muck	Pt	A-8	- - Organic Soil- -			- - - -	- - - -	- - - - -	- - - -	6.3-20.0	.26	5.1-6.0	Very high	High shrink low swell	Severe
Tamba (Ta)	5+	2-3	0-60	Mucky clay	OH	A-7	100	100	100	90-100	75-95	50-70	20-37	0.63-2.0	.15	4.5-6.0	Very high	High shrink low swell	Severe
Tidal Marsh (Td)	5+	0-1	0-60	Stratified mineral and organic matter	OH	A-7	100	100	100	90-100	75-95	50-70	20-37	0.63-2.0	.10	4.5-6.0	Very high	High shrink low swell	Severe
Valdez (Vc)	5+	4-5	0-60	Silty clay loam	CL	A-6	100	100	100	95-100	85-95	20-40	15-30	0.2-0.63	.10	5.6-7.3	Moderate	Moderate	Severe
Valdez (Ve)	5+	3-5	0-40	Silty clay loam	CL	A-6	100	100	100	95-100	85-95	20-40	15-30	0.2-0.63	.09	5.6-7.3	Moderate	Moderate	Severe
			40-60	Clay	CL	A-7	100	100	100	90-100	75-95	41-50	22-40	0.06-0.2	.09	5.6-8.4	Moderate	Moderate	Severe

normally will fall. Plow pans, surface crust and other properties resulting from use of the soils are not considered.

Available water capacity (available moisture capacity) expressed in inches per inch of soil depth, as shown, is the approximate amount of capillary water in the soil when wet to field capacity. When the soil is "air-dry" this amount of water will wet the soil material described to a depth of one inch without deeper percolation.

Salinity of the soil is based on te electrical conductivity of the saturated soil extract, as expressed in millimhos per centimeter (mmhos/cm) at 25° C. Salinity not only affects the suitability of a soil for crop production, but also its stability when used as a construction material and its corrosive potential. Salinity is rated as none (less than 2.0), low (2.0-4.0), moderate (4.0-8.0), high (8.0-16.0), and very high (more than 16.0).

Shrink-swell potential is that quality of the soil that indicates the expected volume change with change in moisture content. This potential is based on volume-change tests, or observance of other physical properties or characteristics of the soil. The volume change behavior of soils is influenced by the amount of moisture change and amount and kind of clay present in the soil. In general, soils that have high shrink-swell potential hazards to the maintenance of structures constructed in, on or with these materials. Building foundations, roads, and other structures may be severely damaged by the shrinking and swelling of soils. The potential is rated low, moderate or high.

Reaction is the degree of acidity or alkalinity of the soil, expressed as a pH value. Reaction affects the potential corrosivity of the soil. Descriptive terms commonly associated with certain ranges in pH are: extremely acid, less than 4.5; very strongly acid, 4.5-5.0; strongly acid 5.1-5.5; moderately acid 5.6-6.0; slightly acid 6.1-6.5; neutral, 6.6-7.3; slightly alkaline, 7.4-7.8; moderately alkaline, 7.9-8.4; strongly alkaline, 8.5-9.0; and very strongly alkaline, greater than 9.1.

Corrosivity, as used here, indicates the potential danger to uncoated steel structures through chemical action that dissolves or weakens the structural material. Corrosivity correlates closely with the physical, chemical and biological characteristics and qualities of the soil.

The soil is evaluated in its undisturbed state as a single unloaded soil. Where structures intersect different soil boundaries the potential of corrosion is greater than in a single soil. The loading of buildings, etc., may alter the soil permeability thereby increasing the corrosion potential. Mechanical agitation or excavation that results in non-uniform mixing of soil horizons may also accelerate the corrosion potential. The use of soil corrosivity interpretations without considering the size of the metallic structure or the differential effects involved through use of different metals may lead to the wrong conclusions. The corrosivity is rated as low, moderate or severe.

ENGINEERING USES OF SOIL

The engineering properties of the soil are particularly important in the planning, designing, construction and maintenance of all engineering structures. The relationship of the soil to the structure may be in the use of it as the basic building material or the foundation upon which the structure is placed. Foundations of structures and structures made of soil (earth material) are as old as human civilization itself. Most of the principles of soil mechanics have been known through decades and perhaps centuries but only in the last 40 or 50 years have they been brought together and understood more fully as "soil mechanics." Only in the last decade has the data in soil survey reports prepared by the United States Department of Agriculture, Soil Conservation Service and cooperating agencies, been used for general engineering interpretation.

This section provides information of special interest to land owners, contractors, planners, and others who use soil as a structural material or as foundation material upon which structures are built. The characteristics and behavior of soils may vary considerably within the confines of an engineering structure, its foundation or borrow area. Many times a less desirable material must be used or the structure relocated in a more desirable soil. This section contains information on those properties of the soils that affect construction and maintenance of roads, pipelines, water storage facilities, erosion control structures, drainage and irrigation systems. Among the soil properties, those most important in engineering are permeability, shear strength, density, shrink-swell potential, water holding capacity, grain size distribution, plasticity and reaction.

Information concerning these and related soil properties are contained in Tables 4, 5, and 6. The basic data used in the preparation of these tables was obtained from the soil map, soil description, and laboratory test data. The soil map was prepared primarily for use as a tool in agricultural soils management but this same data can give general information important to engineering "soil mechanics." The estimates and interpretations of soil properties in these tables can be used to:

1. Make studies that will aid in selecting and developing industrial, business, residential, and recreational sites.
2. Make preliminary estimates of the engineering properties of soils in the general planning of agricultural drainage systems, irrigation systems, ponds, etc.
3. Make preliminary evaluations of soil and ground conditions

TABLE 6
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
CALIFORNIA

Interpretation of engineering properties of the soils in SUISUN MARSH.

Soil series and map symbols (1)	Suitability as source of — Topsoil (2)	Sand and gravel (3)	Road fill (4)	Hydrologic soil group (5)	Soil features affecting — Road location (6)	Water retention: Embankments (7)	Water retention: Reservoir area (8)	Agricultural drainage (9)	Irrigation (10)	Soil limitations for — Septic tank filter field (11)	Sewage Lagoon (12)
JOICE (JA)	Poor, high salinity, low fertility	-	Poor, A-8, organic soil, high water table	D	Organic soil, high water table	Poor stability and compaction characteristics, high shrinkage characteristics, organic material	High permeability, organic matter more than 30%	Perennial high water table, outlets difficult to obtain, organic matter more than 30%	High subsidence characteristics, high salinity, high water table	Severe, high water table	Severe, organic matter more than 15%
JOICE (JB)	Poor, high salinity, low fertility	-	Poor, A-8, A-7, organic soil, high water table	D	Organic soil 0 to 30", high water table	Poor stability and compaction characteristics, high strinkage characteristics, organic material 0 to 30"	Organic matter more than 30% 0 to 30"	Perennial high water table, outlets difficult to obtain, organic matter more than 30% 0 to 30"	High subsidence characteristics 0 to 30", high salinity, high water table	Severe, high water table	Severe, organic matter more than 15%
REYES (RE)	Poor, Very low fertility, saline, very acid	-	Fair to poor, A-6, A-7, high strinkage, high water table	D	Plastic material, seasonal high water table, high shrinkage characteristics	Fair stability & compaction characteristics, high shrinkage characteristics	Slopes 0-2%	Slow permeability, difficult to obtain outlets	Slow intake rate, seasonal high water table, high salinity, very acid	Severe, slow permeability	Slight
SUISUN (SP)	Poor, high salinity, low fertility	-	Poor, A-8, organic soil, high water table	D	Organic soil, perennial high water table	Organic material	Rapid permeability, organic material, slopes 0 to 2%	Difficult to obtain outlets, organic more material	Rapid intake rate, organic material, high salinity, perennial high water table	Severe, permanent high water table	Severe, organic matter more than 15%

TABLE 6 - PAGE 2

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
CALIFORNIA

Interpretation of engineering properties of the soils in SUISUN MARSH

Soil series and map symbols (1)	Suitability as source of — Topsoil (2)	Suitability as source of — Sand and gravel (3)	Suitability as source of — Road fill (4)	Hydrologic soil group (5)	Soil features affecting — Road location (6)	Soil features affecting — Water retention — Embankments (7)	Soil features affecting — Water retention — Reservoir area (8)	Soil features affecting — Agricultural drainage (9)	Soil features affecting — Irrigation (10)	Soil limitations for — Septic tank filter field (11)	Soil limitations for — SEWAGE LAGOON (12)
TAMBA (TA)	Poor, low fertility, strong saline	-	Poor, A-7, high organic content high water table	D	High organic material, perennial high water table	Poor stability and compaction characteristics, high shrinkage characteristics, organic material high	High permeability, organic matter more than 15%, slopes 0 to 2%	Perennial high water table, outlets difficult to obtain	High subsidence characteristics, perennial high water table, strongly saline	severe, permanent high water table	Severe, organic matter more than 15%
TIDAL MARSH (TD)	Poor, very low fertility, strongly saline	-	Poor, A-7, subject to tidal flooding	D	Subject to tidal flooding	Poor stability and compaction characteristics, high shrinkage characteristics	Stratified fine sand, silt, and clay; moderate permeability, slopes 0 to 2%	Not applicable	Not applicable	Severe, permanent high water table	Severe, subject to flooding
VALDEZ (VC)	Poor, low fertility, moderately saline	-	Fair, A-6, seasonal high water table	C	Silty-clayey material, seasonal high water table	Fair to good stability and compaction characteristics	Slopes 0 to 2%	Difficult to obtain outlets, moderately slow permeability	Seasonal high water table, moderately saline	Moderate, Moderately slow permeability	Slight
VALDEZ (VE)	Poor, low fertility, moderately saline	-	Fair, A-6, moderate shrink swell, seasonal high water table	C	Silty-clayey material, seasonal high water table	Fair to good stability and compaction characteristics	Slopes 0 to 2%	Difficult to obtain outlets, slow permeability in subsoil	Moderately saline, seasonal high water table, slow subsoil permeability	Severe, slow permeability	Slight

that will aid in selecting highway, pipeline, and cable locations and in planning detailed investigations at the selected locations.

4. Locate probable sources of construction materials.
5. Supplement the information from other sources to prepare maps or reports useful to engineers.
6. Correlate performance of engineering structures with soil mapping units to develop information for overall planning that will be useful in designing and maintaining certain engineering practices and structures.
7. Develop other preliminary estimates for construction purposes pertinent to the particular area.

The use of the data in Table 4, 5 and 6 and the soil maps will provide a preliminary evaluation of the engineering properties of any particular soil in the county. It is not intended that the information of soil properties contained in this report be specific enough to eliminate the need for on-site sampling and testing of sites for design and construction of particular engineering works.

It should be used primarily in planning more detailed field investigation to determine the in-place condition of soil material at the site of the proposed engineering structures.

ENGINEERING CLASSIFICATION OF SOILS

The two systems most commonly used in classifying samples of soil horizons for engineering are the AASHO system adopted by the American Association of State Highway officials and the Unified System developed by the Corps of Engineers and others.

In the AASHO system, most widely known and used in highway practice, a soil is placed in one of seven basic groups ranging from A-1 through A-8. This is done on the basis of grain-size distribution, liquid limit, and plasticity index. Group A-1 includes gravelly soils of high bearing strength, or the best soils for subgrade (foundation) use. The other extreme is group A-7, clay soils, that have low strength when wet. The best soils are classified as A-1, the next best A-2 and so on to class A-7, the poorest soils for subgrade. Class A-8 soils have organic content greater than 30 percent and are not recommended for subgrade use or embankments.

In the unified system soils are classified according to particle size distribution, plasticity, liquid limit and organic matter (Table 5). Soils are grouped in 15 classes. There are 8 coarse grained soil classes (GW, GP, GM, GC, SW, SP, SM and SC), 6 fine grained soil classes (MC, CL, OC, MH, CH, and OH), and 1 highly organic soil class (Pt).

INTERPRETATION OF ENGINEERING PROPERTIES OF SOILS

Table 6 contains selected information useful to engineers and others who plan to use soil material in construction of roads, farm facilities, buildings, and sewage disposal systems. The specific features or characteristics that may affect the selection, design, construction and maintenance of various measures and the suitability ratings for specific purposes, are listed.

In general, the soil features were rated or shown according to the severity of the problem which might result during the construction or maintenance of an engineering practice. The soil features shown were based on the typical profile of that soil shown in Table 6 and those variations which were felt to be materially different.

Top soil is a term used to designate fertile soil or soil material, ordinarily rich in organic matter, used as a top dressing for lawns, gardens, road banks and the like. The ratings, good, fair, poor, indicate the suitability for such use.

Suitability rating as a source of sand and gravel for concrete, mortar, or plaster. The rating, good, fair, and poor, indicates the suitability for such use.

Road fill is material used to build embankments. The ratings, good, fair, poor, indicate performance of soil material moved from borrow areas for these purposes.

Information useful to engineers in estimating storm runoff from various soils is shown in Table 6 in Hydrologic Soil Group ratings. Four major groups are used. The soils are classified on the basis of intake of water at the end of long duration storms occurring after prior wetting and opportunity for swelling, and without the protective affects of vegetation. The hydrologic groupings are tentative and may change as more data is obtained and evaluated.

Hydrologic soil groups are:

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Road location is influenced by features that relate to the undisturbed soil as they affect construction and maintenance of unsurfaced roads. They could, however, be general indicators as to some of the problems in highway locations.

Water retention embankments serve as dams. The soil features shown of both subsoil and substratum, are those important to the use of soils for constructing embankments.

Water retention reservoir areas are affected mainly by seepage loss of water and the soil features are those that influence such seepage.

Agricultural drainage is influenced by the need for drainage and the soil features that would relate to the effectiveness of a drainage system. These factors which should be taken into consideration are noted.

Irrigation is influenced by the capability of the soil to produce crops. Such features as fertility, water holding capacity, influence of water tables or flooding on crop growth, relative ease with which water can enter the soil and other similar factors are noted.

Septic tank filter fields are affected mainly by permeability, location of water table, slope of the land and susceptibility to flooding.

The interpretations relate to the ability to dispose of the effluents with reasonable uniformity in the soil. Consideration must be given to the contamination hazard of the more porous soils, the degree of limitation (slight, moderate, severe) and the principal reasons for assigning moderate or severe limitations are given.

Sewage lagoons are influenced chiefly by soil features such as permeability, location of water table and slope. These features relate to the ability of the soils to accommodate shallow lakes to hold sewage for the time required for bacterial decomposition. The ability of the soil to act as a floor for the impoundment and the ability of the soil to provide material and a foundation for the embankment were taken into consideration. The degree of limitation (slight, moderate, severe) and the principal reasons for assigning moderate or severe limitations are given.

ENGINEERING INTERPRETATIONS FOR DIKES IN THE SUISUN MARSH STUDY AREA

Dikes and levees are embankments of earth or other suitable materials contructed to protect land against overflows from streams and tides.

Class III dikes, as commonly found in the Suisun Marsh, are embankments which protect agricultural lands of relatively low capacity or improvements of relatively low value. These dikes are limited to low heads of water. The maximum design water stage above ground level, exclusive of crossings at channels, sloughs, swales, and gullies, is:

1. For mineral soils - 6 feet
2. For organic soils - 4 feet

Dikes in the Suisun Marsh area usually are constructed of fill material borrowed adjacent and parallel to the line of the dike. Soil characteristics can assist in evaluating soil conditions along the line of the dike and can be used as a guide to soil stability and permeability. The suitability of soils in the Suisun Marsh for construction of Class III levees is indicated in Table 7a with soil classification in Table 7b.

TABLE 7a. SUITABILITY OF SOILS IN THE SUISUN MARSH STUDY AREA

FOR CLASS III DIKES

UNIFIED GROUP SYMBOL	SOIL DESCRIPTION	PERMEABILITY AND SLOPES	SUITABILITY FOR CLASS III DIKES
CL	Inorganic clays of low to medium plasticity, silty clays.	Slow permeability	STABLE - Adequate for all stages. Fair foundation bearing. Fair compaction with rubber tires. Use dumped fill on lower stages only.
OH	Organic clays having medium to high plasticity and organic silts.	Very slow permeability- use for low stages only. Use flat slopes.	VERY LOW STABILITY - Adequate only for low stages and can use dumped fill. Has poor foundation bearing and compaction.
Pt	Peat and other highly organic soils.	Variable permeability- may vary significantly between vertical and horizontal.	VERY LOW STABILITY- Use only for temporary dikes. Remove from foundation for mineral soil dikes.

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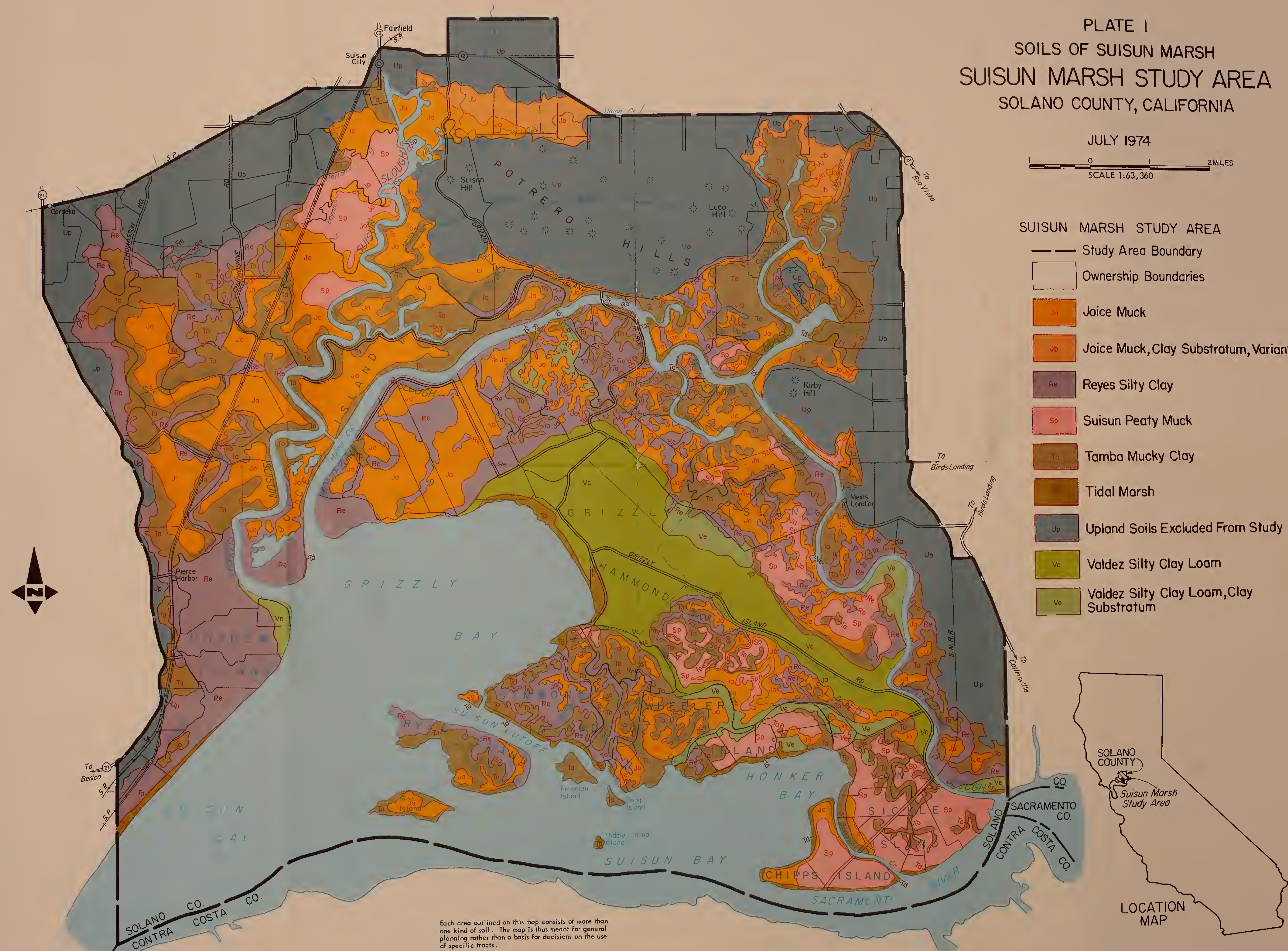

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PLATE 6

OWNERSHIP MAP
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA

MARCH 1974

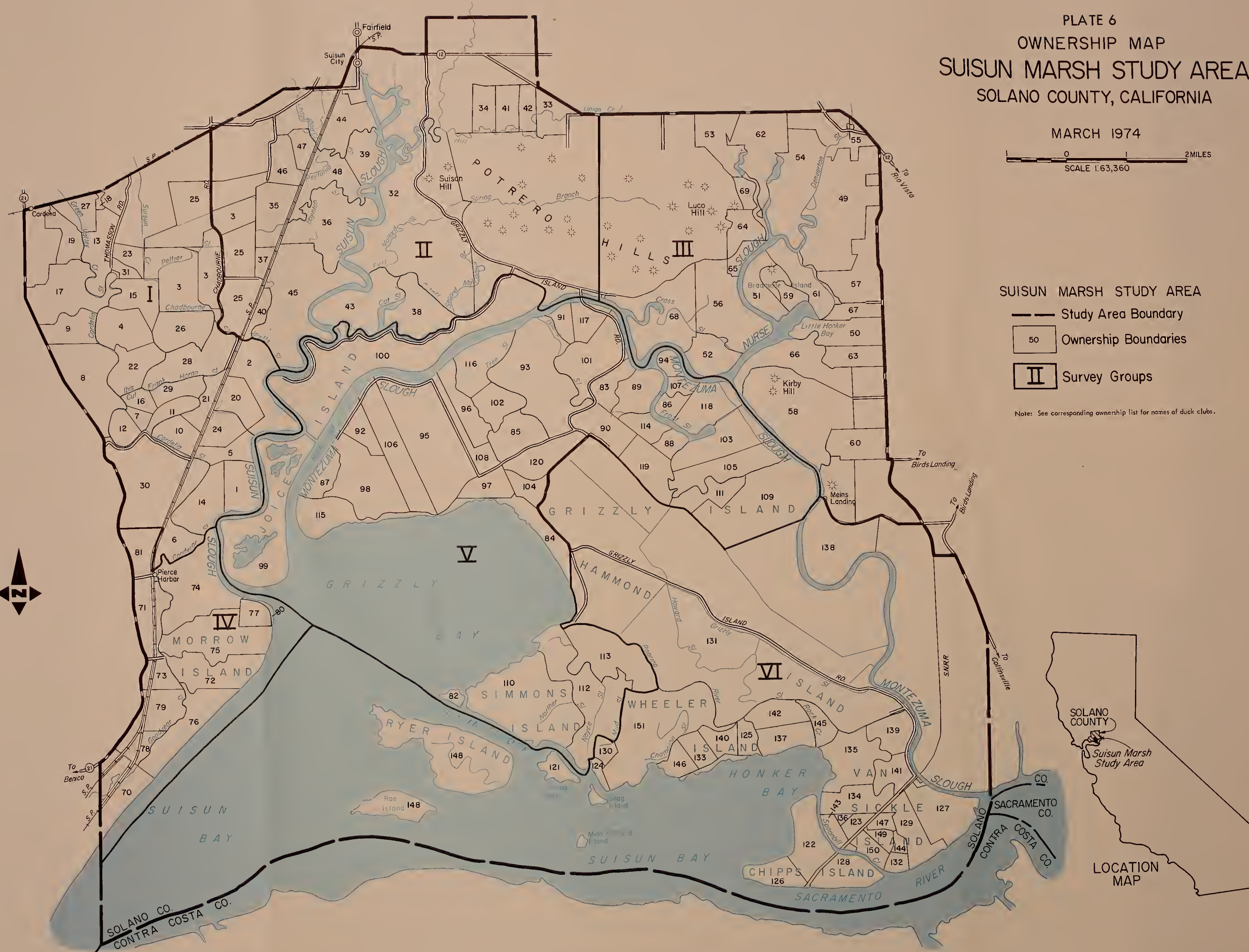

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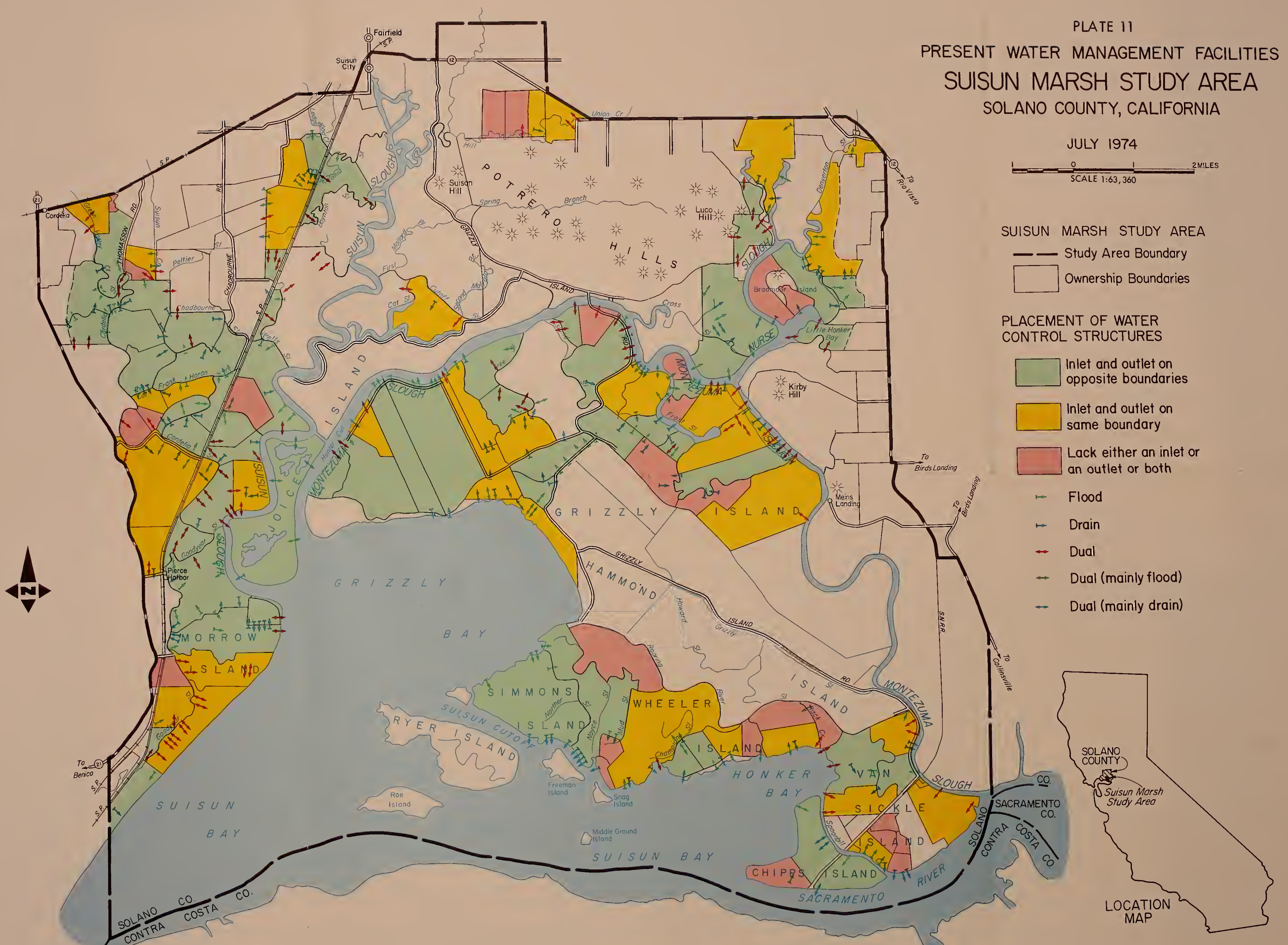
PLATE 11

PRESENT WATER MANAGEMENT FACILITIES
SUISUN MARSH STUDY AREA
SOLANO COUNTY, CALIFORNIA

JULY 1974



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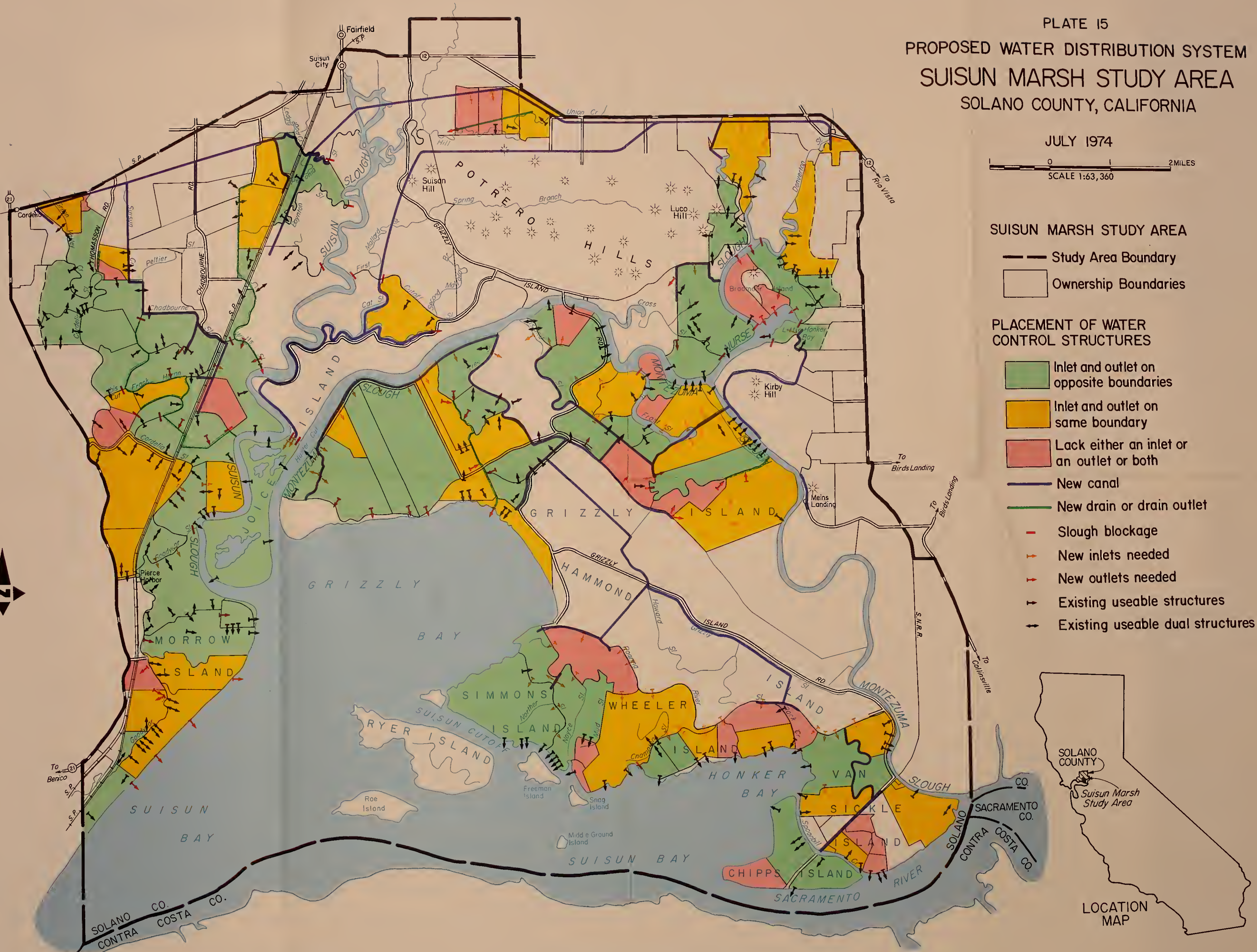

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TABLE 7b. CLASSIFICATION OF SUISUN MARSH SOILS

Soil Symbol		Unified Symbol
Ja	Joice clayey muck	Pt
Jb	Joice Variant	
	clayey muck 0-30"	Pt
	clay 30-60"	CL
Re	Reyes silty clay	CL
Sp	Suisun muck	Pt
Ta	Tamba mucky clay	OH
Td	Tidal Marsh	OH
Vc	Valdez silty clay loam	CL
Ve	Valdez silt clay loam	CL
	clay substrata	CL